Form **990-EZ**

Department of the Treasury
Internal Revenue Service

Short Form
Return of Organization Exempt From Income Tax

Under section 501(c), 527, or 4947(a)(1) of the Internal Revenue Code (except black lung benefit trust or private foundation)

▶ Sponsoring organizations of donor advised funds and controlling organizations as defined in section 512(b)(13) must file Form 990. All other organizations with gross receipts less than $500,000 and total assets less than $1,250,000 at the end of the year may use this form.

▶ *The organization may have to use a copy of this return to satisfy state reporting requirements.*

OMB No. 1545-1150

2009

Open to Public Inspection

A For the 2009 calendar year, or tax year beginning , 2009, and ending , 20

B Check if applicable:
- ☐ Address change
- ☐ Name change
- ☐ Initial return
- ☐ Terminated
- ☐ Amended return
- ☐ Application pending

Please use IRS label or print or type. See Specific Instructions.

C Name of organization: NORTHEAST CONSORTIUM FOR ENGINEERING EDUCATION (NCEE)

Number and street (or P.O. box, if mail is not delivered to street address): 1156-1160 WALNUT GROVE ROAD — Room/suite: N/A

City or town, state or country, and ZIP + 4: BRIDGEPORT, NY 13030-9760

D Employer identification number: 22-2238085

E Telephone number: (804) 742-5611

F Group Exemption Number ▶ N/A

● *Section 501(c)(3) organizations and 4947(a)(1) nonexempt charitable trusts must attach a completed Schedule A (Form 990 or 990-EZ).*

G Accounting Method: ☒ Cash ☐ Accrual Other (specify) ▶

H Check ▶ ☒ if the organization is **not** required to attach Schedule B (Form 990, 990-EZ, or 990-PF)

I Website: ▶ N/A

J Tax-exempt status (check only one) — ☒ 501(c) (3) ◀ (insert no.) ☐ 4947(a)(1) or ☐ 527

K Check ▶ ☐ if the organization is not a section 509(a)(3) supporting organization **and** its gross receipts are normally **not** more than $25,000. A Form 990-EZ or Form 990 return is not required, but if the organization chooses to file a return, be sure to file a complete return.

L Add lines 5b, 6b, and 7b, to line 9 to determine gross receipts; if $500,000 or more, file Form 990 instead of Form 990-EZ ▶ $

Part I — Revenue, Expenses, and Changes in Net Assets or Fund Balances (See the instructions for Part I.)

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Revenue	1	Contributions, gifts, grants, and similar amounts received SEE ATTACHMENTS FOR EFFORT CONTRIBUTED			1	-0-
	2	Program service revenue including government fees and contracts			2	-0-
	3	Membership dues and assessments			3	-0-
	4	Investment income			4	31,499.36
	5a	Gross amount from sale of assets other than inventory	5a	-0-		
	b	Less: cost or other basis and sales expenses	5b	-0-		
	c	Gain or (loss) from sale of assets other than inventory (Subtract line 5b from line 5a)			5c	-0-
	6	Special events and activities (complete applicable parts of Schedule G). If any amount is from gaming, check here ▶ ☐				
	a	Gross revenue (not including $ -0- of contributions reported on line 1)	6a	-0-		
	b	Less: direct expenses other than fundraising expenses	6b	-0-		
	c	Net income or (loss) from special events and activities (Subtract line 6b from line 6a)			6c	-0-
	7a	Gross sales of inventory, less returns and allowances	7a	-0-		
	b	Less: cost of goods sold	7b	-0-		
	c	Gross profit or (loss) from sales of inventory (Subtract line 7b from line 7a)			7c	-0-
	8	Other revenue (describe ▶ SEE ATTACHMENTS FOR CONTRIBUTED EFFORT)			8	-0-
	9	**Total revenue.** Add lines 1, 2, 3, 4, 5c, 6c, 7c, and 8 ▶			9	31,499.36
Expenses	10	Grants and similar amounts paid (attach schedule)			10	-0-
	11	Benefits paid to or for members			11	-0-
	12	Salaries, other compensation, and employee benefits			12	40,475.54
	13	Professional fees and other payments to independent contractors			13	-0-
	14	Occupancy, rent, utilities, and maintenance 2009 RENT DEFERRED TO LATER YEARS			14	258.64
	15	Printing, publications, postage, and shipping			15	383.53
	16	Other expenses (describe ▶ NONE)			16	-0-
	17	**Total expenses.** Add lines 10 through 16 ▶			17	41,117.71
Net Assets	18	Excess or (deficit) for the year (Subtract line 17 from line 9)			18	(9,618.35)
	19	Net assets or fund balances at beginning of year (from line 27, column (A)) (must agree with end-of-year figure reported on prior year's return)			19	1,168,821.96
	20	Other changes in net assets or fund balances (attach explanation) MARKET VALUE OF INVESTMENTS FLUCTUATE APPRECIATION			20	23,468.58
	21	Net assets or fund balances at end of year. Combine lines 18 through 20 ▶			21	1,182,672.19

Part II — Balance Sheets. If Total assets on line 25, column (B) are $1,250,000 or more, file Form 990 instead of Form 990-EZ.

Line	(See the instructions for Part II.)	(A) Beginning of year	Line	(B) End of year
22	Cash, savings, and investments SEE ATTACHMENTS	1,502,833.08	22	1,554,189.23
23	Land and buildings	-0-	23	-0-
24	Other assets (describe ▶ NONE)	-0-	24	-0-
25	**Total assets**	1,502,833.08	25	1,554,189.23
26	**Total liabilities** (describe ▶ SEE ATTACHMENTS)	334,011.22	26	371,517.04
27	**Net assets or fund balances** (line 27 of column (B) **must** agree with line 21)	1,168,821.96	27	1,182,672.19

For Privacy Act and Paperwork Reduction Act Notice, see the separate instructions. Cat. No. 10642I Form **990-EZ** (2009)

SCANNED APR 07 2010

Part III **Statement of Program Service Accomplishments** (See the instructions for Part III.)

What is the organization's primary exempt purpose? Scholarly Research/Professional Development

Describe what was achieved in carrying out the organization's exempt purposes. In a clear and concise manner, describe the services provided, the number of persons benefited, and other relevant information for each program title.

			Expenses (Required for section 501(c)(3) and 501(c)(4) organizations and section 4947(a)(1) trusts; optional for others.)
28	PUBLICATION OF QUARTERLY "COMPUTERS IN EDUCATION JOURNAL" (SEE COPY ATTACHED); OFFERING PROFESSIONAL DEVELOPMENT COURSES; PUBLICATION OF PROFESSIONAL/Scholarly BOOKS. (Grants $ -0-) If this amount includes foreign grants, check here ▶ ☐	28a	41,117.71
29	(Grants $) If this amount includes foreign grants, check here ▶ ☐	29a	
30	(Grants $) If this amount includes foreign grants, check here ▶ ☐	30a	
31	Other program services (attach schedule) (Grants $) If this amount includes foreign grants, check here ▶ ☐	31a	
32	**Total program service expenses** (add lines 28a through 31a) ▶	32	41,117.71

Part IV **List of Officers, Directors, Trustees, and Key Employees.** List each one even if not compensated. (See the instructions for Part IV.)

(a) Name and address	(b) Title and average hours per week devoted to position	(c) Compensation (If not paid, enter -0-.)	(d) Contributions to employee benefit plans & deferred compensation	(e) Expense account and other allowances
DR. W.W. EVERETT, JR., 1101 MASSACHUSETTS AVENUE, ST. CLOUD, FL	CHAIRMAN -20-	-0-	-0-	-0-
DR. V.W. EVELEIGH, 2315 PLATINUM DRIVE, SUN CITY, FL	DIRECTOR -2-	-0-	-0-	-0-
WOODROW W. EVERETT, III, 1156 WALNUT GROVE ROAD, Bridgeport, NY	MAN DIRECTOR -25	$28,917.90	$11,557.64	-0-

Part V Other Information (Note the statement requirements in the instructions for Part V.)

			Yes	No
33	Did the organization engage in any activity not previously reported to the IRS? If "Yes," attach a detailed description of each activity	33		X
34	Were any changes made to the organizing or governing documents? If "Yes," attach a conformed copy of the changes	34		X
35	If the organization had income from business activities, such as those reported on lines 2, 6a, and 7a (among others), but not reported on Form 990-T, attach a statement explaining why the organization did not report the income on Form 990-T.			
a	Did the organization have unrelated business gross income of $1,000 or more or was it subject to section 6033(e) notice, reporting, and proxy tax requirements?	35a		X
b	If "Yes," has it filed a tax return on **Form 990-T** for this year? N/A.	35b		
36	Did the organization undergo a liquidation, dissolution, termination, or significant disposition of net assets during the year? If "Yes," complete applicable parts of Schedule N	36		X
37a	Enter amount of political expenditures, direct or indirect, as described in the instructions. ▶ 37a NONE			
b	Did the organization file **Form 1120-POL** for this year?	37b		X
38a	Did the organization borrow from, or make any loans to, any officer, director, trustee, or key employee or were any such loans made in a prior year and still outstanding at the end of the period covered by this return?	38a		X
b	If "Yes," complete Schedule L, Part II and enter the total amount involved 38b N/A			
39	Section 501(c)(7) organizations. Enter:			
a	Initiation fees and capital contributions included on line 9 39a NONE			
b	Gross receipts, included on line 9, for public use of club facilities 39b NONE			
40a	Section 501(c)(3) organizations. Enter amount of tax imposed on the organization during the year under: section 4911 ▶ NONE ; section 4912 ▶ NONE ; section 4955 ▶ NONE			
b	Section 501(c)(3) and 501(c)(4) organizations. Did the organization engage in any section 4958 excess benefit transaction during the year or is it aware that it engaged in an excess benefit transaction with a disqualified person in a prior year, and that the transaction has not been reported on any of the organization's prior Forms 990 or 990-EZ? If "Yes," complete Schedule L, Part I	40b		X
c	Section 501(c)(3) and 501(c)(4) organizations. Enter amount of tax imposed on organization managers or disqualified persons during the year under sections 4912, 4955, and 4958 ▶ NONE			
d	Section 501(c)(3) and 501(c)(4) organizations. Enter amount of tax on line 40c reimbursed by the organization ▶ NONE			
e	All organizations. At any time during the tax year, was the organization a party to a prohibited tax shelter transaction? If "Yes," complete Form 8886-T.	40e		X

41 List the states with which a copy of this return is filed. ▶ NONE

42a The organization's books are in care of ▶ WOODROW W. EVERETT, III Telephone no. ▶ (804) 742-5611
Located at ▶ 1156 WALNUT GROVE ROAD, BRIDGEPORT, NY ZIP + 4 ▶ 13030-9760

			Yes	No
b	At any time during the calendar year, did the organization have an interest in or a signature or other authority over a financial account in a foreign country (such as a bank account, securities account, or other financial account)?	42b		X
	If "Yes," enter the name of the foreign country: ▶ See the instructions for exceptions and filing requirements for **Form TD F 90-22.1, Report of Foreign Bank and Financial Accounts.**			
c	At any time during the calendar year, did the organization maintain an office outside of the U.S.? If "Yes," enter the name of the foreign country: ▶ N/A	42c		X

43 Section 4947(a)(1) nonexempt charitable trusts filing Form 990-EZ in lieu of **Form 1041**—Check here ▶ ☐
and enter the amount of tax-exempt interest received or accrued during the tax year ▶ 43 N/A

			Yes	No
44	Did the organization maintain any donor advised funds? If "Yes," Form 990 must be completed instead of Form 990-EZ	44		X
45	Is any related organization a controlled entity of the organization within the meaning of section 512(b)(13)? If "Yes," Form 990 must be completed instead of Form 990-EZ	45		X

Part VI **Section 501(c)(3) organizations and section 4947(a)(1) nonexempt charitable trusts only.** All section 501(c)(3) organizations and section 4947(a)(1) nonexempt charitable trusts must answer questions 46–49b and complete the tables for lines 50 and 51.

			Yes	No
46	Did the organization engage in direct or indirect political campaign activities on behalf of or in opposition to candidates for public office? If "Yes," complete Schedule C, Part I	46		X
47	Did the organization engage in lobbying activities? If "Yes," complete Schedule C, Part II	47		X
48	Is the organization a school as described in section 170(b)(1)(A)(ii)? If "Yes," complete Schedule E	48		X
49a	Did the organization make any transfers to an exempt non-charitable related organization?	49a		X
b	If "Yes," was the related organization a section 527 organization?	49b		X

50 Complete this table for the organization's five highest compensated employees (other than officers, directors, trustees and key employees) who each received more than $100,000 of compensation from the organization. If there is none, enter "None."

(a) Name and address of each employee paid more than $100,000	(b) Title and average hours per week devoted to position	(c) Compensation	(d) Contributions to employee benefit plans & deferred compensation	(e) Expense account and other allowances
NONE	N/A	N/A	N/A	N/A

f Total number of other employees paid over $100,000 ▶ NONE

51 Complete this table for the organization's five highest compensated independent contractors who each received more than $100,000 of compensation from the organization. If there is none, enter "None."

(a) Name and address of each independent contractor paid more than $100,000	(b) Type of service	(c) Compensation
NONE	N/A	N/A

d Total number of other independent contractors each receiving over $100,000 ▶ NONE

Sign Here

Under penalties of perjury, I declare that I have examined this return, including accompanying schedules and statements, and to the best of my knowledge and belief, it is true, correct, and complete. Declaration of preparer (other than officer) is based on all information of which preparer has any knowledge

▶ Woodrow W. Everett Jr. | 3/12/2010
Signature of officer | Date

▶ WOODROW W. EVERETT, JR., CHAIRMAN
Type or print name and title

Paid Preparer's Use Only

Preparer's signature ▶	Date	Check if self-employed ▶ ☐	Preparer's identifying number (See instructions)
Firm's name (or yours if self-employed), address, and ZIP + 4 ▶		EIN ▶	
		Phone no. ▶	

May the IRS discuss this return with the preparer shown above? See instructions ▶ ☐ Yes ☐ No

SCHEDULE A
(Form 990 or 990-EZ)

Department of the Treasury
Internal Revenue Service

Public Charity Status and Public Support

Complete if the organization is a section 501(c)(3) organization or a section 4947(a)(1) nonexempt charitable trust.

▶ Attach to Form 990 or Form 990-EZ. ▶ See separate instructions.

OMB No 1545-0047

2009

Open to Public Inspection

Name of the organization NORTHEAST CONSORTIUM FOR ENGINEERING EDUCATION (NCEE)

Employer identification number 22 : 2238085

Part I Reason for Public Charity Status (All organizations must complete this part.) See instructions.

The organization is not a private foundation because it is: (For lines 1 through 11, check only one box.)

1 ☐ A church, convention of churches, or association of churches described in **section 170(b)(1)(A)(i).**

2 ☐ A school described in **section 170(b)(1)(A)(ii).** (Attach Schedule E)

3 ☐ A hospital or a cooperative hospital service organization described in **section 170(b)(1)(A)(iii).**

4 ☐ A medical research organization operated in conjunction with a hospital described in **section 170(b)(1)(A)(iii).** Enter the hospital's name, city, and state: ____________

5 ☐ An organization operated for the benefit of a college or university owned or operated by a governmental unit described in **section 170(b)(1)(A)(iv).** (Complete Part II.)

6 ☐ A federal, state, or local government or governmental unit described in **section 170(b)(1)(A)(v).**

7 ☐ An organization that normally receives a substantial part of its support from a governmental unit or from the general public described in **section 170(b)(1)(A)(vi).** (Complete Part II.)

8 ☐ A community trust described in **section 170(b)(1)(A)(vi).** (Complete Part II.)

9 ☐ An organization that normally receives: (1) more than 33⅓ % of its support from contributions, membership fees, and gross receipts from activities related to its exempt functions—subject to certain exceptions, and (2) no more than 33⅓ % of its support from gross investment income and unrelated business taxable income (less section 511 tax) from businesses acquired by the organization after June 30, 1975. See **section 509(a)(2).** (Complete Part III.)

10 ☐ An organization organized and operated exclusively to test for public safety. See **section 509(a)(4).**

11 ☒ An organization organized and operated exclusively for the benefit of, to perform the functions of, or to carry out the purposes of one or more publicly supported organizations described in section 509(a)(1) or section 509(a)(2). See **section 509(a)(3).** Check the box that describes the type of supporting organization and complete lines 11e through 11h.

a ☐ Type I **b** ☐ Type II **c** ☐ Type III–Functionally integrated **d** ☒ Type III–Other

e ☐ By checking this box, I certify that the organization is not controlled directly or indirectly by one or more disqualified persons other than foundation managers and other than one or more publicly supported organizations described in section 509(a)(1) or section 509(a)(2).

f If the organization received a written determination from the IRS that it is a Type I, Type II, or Type III supporting organization, check this box . . . ☐

g Since August 17, 2006, has the organization accepted any gift or contribution from any of the following persons?

		Yes	No
(i) A person who directly or indirectly controls, either alone or together with persons described in (ii) and (iii) below, the governing body of the supported organization?	11g(i)		
(ii) A family member of a person described in (i) above?	11g(ii)		
(iii) A 35% controlled entity of a person described in (i) or (ii) above?	11g(iii)		

h Provide the following information about the supported organization(s).

(i) Name of supported organization	(ii) EIN	(iii) Type of organization (described on lines 1–9 above or IRC section **(see instructions)**)	(iv) Is the organization in col. (i) listed in your governing document? Yes	(iv) No	(v) Did you notify the organization in col (i) of your support? Yes	(v) No	(vi) Is the organization in col. (i) organized in the U.S ? Yes	(vi) No	(vii) Amount of support
ASEE (AMERICAN SOCIETY FOR ENGINEERING EDUCATION - JOURNAL	37-0730114	9		X	X		X		$41,117.71
U.S. NAVAL ACADEMY	02-0485760	6		X		X	X		NOT DETAILED. SEE 1ST LINE ABOVE
CENTRAL CONN STATE U (VIA EBSCO)	22-927638	2		X		X	X		NOT DETAILED. SEE 1ST LINE ABOVE
Georgia STATE UNIV (VIA EBSCO)	58-6002030	2		X		X	X		NOT DETAILED. SEE 1ST LINE ABOVE
ATLANTA UNIV (VIA EBSCO)	22-927638	2		X		X	X		NOT DETAILED. SEE 1ST LINE ABOVE
SEE ~~ATTACHMENTS~~ FOR COMPLETE LISTING Total FOR JOURNAL									$41,117.71

Part II **Support Schedule for Organizations Described in Sections 170(b)(1)(A)(iv) and 170(b)(1)(A)(vi)** (Complete only if you checked the box on line 5, 7, or 8 of Part I.)

Section A. Public Support

Calendar year (or fiscal year beginning in) ▶	(a) 2005	(b) 2006	(c) 2007	(d) 2008	(e) 2009	(f) Total
1 Gifts, grants, contributions, and membership fees received. (Do not include any "unusual grants")	-0- #	-0- #	57,151.87 *	40,234.28 *	50,825.72 *	148,211.87
2 Tax revenues levied for the organization's benefit and either paid to or expended on its behalf	-0-	-0-	-0-	-0-	-0-	-0-
3 The value of services or facilities furnished by a governmental unit to the organization without charge	-0-	-0-	-0-	-0-	-0-	-0-
4 **Total.** Add lines 1 through 3	-0-	-0-	57,151.87	40,234.28	50,825.72	148,211.87
5 The portion of total contributions by each person (other than a governmental unit or publicly supported organization) included on line 1 that exceeds 2% of the amount shown on line 11, column (f)						(43,502.06)
6 **Public support.** Subtract line 5 from line 4.						104,709.81

Section B. Total Support

Calendar year (or fiscal year beginning in) ▶	(a) 2005	(b) 2006	(c) 2007	(d) 2008	(e) 2009	(f) Total
7 Amounts from line 4	-0-	-0-	57,151.89	40,234.28	50,825.47	148,211.87
8 Gross income from interest, dividends, payments received on securities loans, rents, royalties and income from similar sources	37,384.30	44,007.93	52,977.41	43,524.41	31,444.36	209,398.91
9 Net income from unrelated business activities, whether or not the business is regularly carried on	1,698.34	-0-	2,721.34	4,154.95	-0-	8,594.63
10 Other income. Do not include gain or loss from the sale of capital assets (Explain in Part IV.)	-0-	-0-	-0-	-0-	-0-	-0-
11 **Total support.** Add lines 7 through 10						366,185.41

12 Gross receipts from related activities, etc. (see instructions) . . . 12 -0-

13 **First five years.** If the Form 990 is for the organization's first, second, third, fourth, or fifth tax year as a section 501(c)(3) organization, check this box and **stop here** . . . ▶ ☐

Section C. Computation of Public Support Percentage

14 Public support percentage for 2009 (line 6, column (f) divided by line 11, column (f)) . . . 14 28.6 %

15 Public support percentage from 2008 Schedule A, Part II, line 14 . . . 15 34.2 %

16a **33⅓ % support test—2009.** If the organization did not check the box on line 13, and line 14 is 33⅓ % or more, check this box and **stop here.** The organization qualifies as a publicly supported organization . . . ▶ ☐

b **33⅓ % support test—2008.** If the organization did not check a box on line 13 or 16a, and line 15 is 33⅓ % or more, check this box and **stop here.** The organization qualifies as a publicly supported organization . . . ▶ ☒

17a **10%-facts-and-circumstances test—2009.** If the organization did not check a box on line 13, 16a, or 16b, and line 14 is 10% or more, and if the organization meets the "facts-and-circumstances" test, check this box and **stop here.** Explain in Part IV how the organization meets the "facts-and-circumstances" test. The organization qualifies as a publicly supported organization . . ▶ ☐

b **10%-facts-and-circumstances test—2008.** If the organization did not check a box on line 13, 16a, 16b, or 17a, and line 15 is 10% or more, and if the organization meets the "facts-and-circumstances" test, check this box and **stop here.** Explain in Part IV how the organization meets the "facts-and-circumstances" test. The organization qualifies as a publicly supported organization ▶ ☐

18 **Private foundation.** If the organization did not check a box on line 13, 16a, 16b, 17a, or 17b, check this box and see instructions ▶ ☐

NOT DOCUMENTED IN FORM 990 SUBMISSIONS
* DOCUMENTED IN FORM 990-EZ FORM

Part III **Support Schedule for Organizations Described in Section 509(a)(2)** N/A
(Complete only if you checked the box on line 9 of Part I.)

Section A. Public Support

Calendar year (or fiscal year beginning in) ▶	(a) 2005	(b) 2006	(c) 2007	(d) 2008	(e) 2009	(f) Total
1 Gifts, grants, contributions, and membership fees received (Do not include any "unusual grants.")						
2 Gross receipts from admissions, merchandise sold or services performed, or facilities furnished in any activity that is related to the organization's tax-exempt purpose						
3 Gross receipts from activities that are not an unrelated trade or business under section 513						
4 Tax revenues levied for the organization's benefit and either paid to or expended on its behalf						
5 The value of services or facilities furnished by a governmental unit to the organization without charge						
6 **Total.** Add lines 1 through 5						
7a Amounts included on lines 1, 2, and 3 received from disqualified persons						
b Amounts included on lines 2 and 3 received from other than disqualified persons that exceed the greater of \$5,000 or 1% of the amount on line 13 for the year						
c Add lines 7a and 7b						
8 **Public support** (Subtract line 7c from line 6.)						

Section B. Total Support

Calendar year (or fiscal year beginning in) ▶	(a) 2005	(b) 2006	(c) 2007	(d) 2008	(e) 2009	(f) Total
9 Amounts from line 6						
10a Gross income from interest, dividends, payments received on securities loans, rents, royalties and income from similar sources						
b Unrelated business taxable income (less section 511 taxes) from businesses acquired after June 30, 1975						
c Add lines 10a and 10b						
11 Net income from unrelated business activities not included in line 10b, whether or not the business is regularly carried on						
12 Other income. Do not include gain or loss from the sale of capital assets (Explain in Part IV.)						
13 **Total support.** (Add lines 9, 10c, 11, and 12.)						

14 **First five years.** If the Form 990 is for the organization's first, second, third, fourth, or fifth tax year as a section 501(c)(3) organization, check this box and **stop here** ▶ ☐

Section C. Computation of Public Support Percentage

15 Public support percentage for 2009 (line 8, column (f) divided by line 13, column (f)) | 15 | %
16 Public support percentage from 2008 Schedule A, Part III, line 15 | 16 | %

Section D. Computation of Investment Income Percentage

17 Investment income percentage for **2009** (line 10c, column (f) divided by line 13, column (f)) | 17 | %
18 Investment income percentage from **2008** Schedule A, Part III, line 17 | 18 | %

19a **33⅓ % support tests—2009.** If the organization did not check the box on line 14, and line 15 is more than 33⅓ %, and line 17 is not more than 33⅓ %, check this box and **stop here.** The organization qualifies as a publicly supported organization ▶ ☐

b **33⅓ % support tests—2008.** If the organization did not check a box on line 14 or line 19a, and line 16 is more than 33⅓ %, and line 18 is not more than 33⅓ %, check this box and **stop here.** The organization qualifies as a publicly supported organization ▶ ☐

20 **Private foundation.** If the organization did not check a box on line 14, 19a, or 19b, check this box and see instructions ▶ ☐

Part IV **Supplemental Information.** Complete this part to provide the explanations required by Part II, line 10; Part II, line 17a or 17b; and Part III, line 12. Provide any other additional information. See instructions.

NCEE
Income Statement as of 12/31/09
3:40 PM

Income Statement for the Period from 1/1/89 to 12/31/09.

Revenue from Sales	Actual
Revenue from Sales	0.00
Less Sales discount	0.00
Net Sales	0.00
Cost of Goods Sold	
Opening Inventory	0.00
Cost of Goods Available for Sale	0.00
Less Current Inventory	0.00
Cost of Goods Sold	0.00
Gross Profit	0.00
Expenses	
Facilities	258.64
G&A Cost-Share	50825.77
G&A Employer FICA	2212.22
G&A PDSL	2514.60
G&A PDSL FICA	192.35
G&A SEP	3457.61
G&A Time	25146.00
G&A Vacation & Sick	3771.90
Health Insurance	3180.86
Journal Cost-Share	54446 94
Office Supplies	127.36
Postage	256.17
Public Inform. Cost-Share	1939.94
Short Course Cost-Share	9440.93
Total Expenses	157771.29
Total Income from Operations	(157771.29)
Other Income	
Contributed Effort	116653.58
Interest	18.32
Rebates	50.00
Total Other Income	116721.90
Net Income	(41049.39)

NCEE
Balance Sheet as of 12/31/09
3:40 PM

Assets	
Current Assets	Actual
Cash 1	1529.34
Operating Acct. Fluctuation	(0.10)
Tax-Tel Acct.	5246.28
Eveleigh Chair	1168.00
Strait Chair	1000.00
Investment (NCEE, FL)	92666.27
Cash Value, Life Insurance	144229.75
Bank Error	(13.62)
Express Mail Account	312.82
Fed 941 OverPay	26.14
Total Current Assets	246164.88
Fixed Assets	
Total Fixed Assets	0.00
Total Assets	246164.88
Liabilities	
Current Liabilities	
NCEE, FL Payable	(4.20)
Everett Chair Transfer	201133.75
PDSL Payable	11323.08
Employer FICA Payable	43.63
PDSL FICA Payable	848.58
Eveleigh Chair Endowment	1168.00
Strait Chair Endowment	1000.00
Deferred Compensation	156000.00
Equity Funds	(32251.32)
Total Current Liabilities	339261.52
Long-Term Liabilities	
Total Long-term Liabilities	0.00
Total Liabilities	339261.52
Owners Equity	
Equity Accounts	
Retained Earnings	(52047.25)
Net Income	(41049.39)
Total Equity Accounts	(93096.64)
Total Liabilities and Owners Equity	246164.88

NCEE
Trial Balance as of 12/31/09
3:40 PM

Trial Balance for Year to Date.

Account#	Name	Debit	Credit
1010	Cash 1	1529.34	
1013	Operating Acct. Fl...		0.10
1014	Tax-Tel Acct.	5246.28	
1015	Eveleigh Chair	1168.00	
1016	Strait Chair	1000.00	
1017	Investment (NCEE...	92666.27	
1021	Cash Value, Life In...	144229.75	
1022	Bank Error		13.62
1023	Express Mail Acco...	312.82	
1114	Fed 941 OverPay	26.14	
2000	NCEE, FL Payable	4.20	
2005	Everett Chair Tra...		201133.75
2040	PDSL Payable		11323.08
2110	Employer FICA Pa...		43.63
2120	PDSL FICA Payable		848.58
2200	Eveleigh Chair End...		1168.00
2201	Strait Chair Endo...		1000.00
2206	Deferred Compens...		156000.00
3010	Equity Funds	32251.32	
4015	Rebates		50.00
4020	Interest		18.32
4060	Contributed Effort		116653.58
6002	Facilities	258.64	
6006	Office Supplies	127.36	
6007	Postage	256.17	
6010	Health Insurance	3180.86	
6040	G&A Time	25146.00	
6041	G&A Cost-Share	50825.77	
6042	G&A Vacation & Sick	3771.90	
6043	G&A PDSL	2514.60	
6045	G&A SEP	3457.61	
6047	G&A Employer FICA	2212.22	
6048	G&A PDSL FICA	192.35	
6061	Journal Cost-Share	54446.94	
6062	Short Course Cost...	9440.93	
6063	Public Inform. Cos...	1939.94	
re	Retained Earnings	52047.25	
		488252.66	488252.66

Everett Endowed Chair
Trial Balance as of 12/31/09
3:39 PM

Trial Balance for Year to Date.

Account#	Name	Debit	Credit
1010	Cash 1	73706.21	
1021 RTS	Everett Endowed C..	1069888.21	
2005	NCEE Transfer	205133.75	
2020	Everett Chair Endo...		887891.05
2021 Adj	Everett Chair Adju...		66760.10
3010	Equity Funds		3135.00
4020	Interest Income		29779.54
4025	Dividend Income		1646.50
re	Retained Earnings		359515.98
		1348728.17	1348728.17

Everett Endowed Chair
Income Statement as of 12/31/09
3:39 PM

Income Statement for the Period from 1/1/89 to 12/31/09.

Revenue from Sales	Actual
Revenue from Sales	0.00
Less Sales discount	0.00
Net Sales	0.00
Cost of Goods Sold	
Opening Inventory	0.00
Cost of Goods Available for Sale	0.00
Less Current Inventory	0.00
Cost of Goods Sold	0.00
Gross Profit	0.00
Expenses	
Total Expenses	0.00
Total Income from Operations	0.00
Other Income	
Dividend Income	1646.50
Interest Income	29779.54
Total Other Income	31426.04
Net Income	31426.04

Everett Endowed Chair
Balance Sheet as of 12/31/09
3:39 PM

Assets	
Current Assets	Actual
Cash 1	73706.21
Everett Endowed Chair	1069888.21
Total Current Assets	1143594.42
Fixed Assets	
Total Fixed Assets	0.00
Total Assets	1143594.42
Liabilities	
Current Liabilities	
NCEE Transfer	(205133.75)
Everett Chair Endowment	887891.05
Everett Chair Adjustments	66760.10
Total Current Liabilities	749517.40
Long-Term Liabilities	
Total Long-term Liabilities	0.00
Total Liabilities	749517.40
Owners Equity	
Equity Accounts	
Equity Funds	3135.00
Retained Earnings	359515.98
Net Income	31426.04
Total Equity Accounts	394077.02
Total Liabilities and Owners Equity	1143594.42

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COMPUTERS IN EDUCATION JOURNAL

COMPUTERS IN EDUCATION DIVISION OF ASEE
VOL. XVIIII NO. 2 APRIL - JUNE 2009 JOURNAL

CONTENTS

Statement of Purpose for CoED

The Computers in Education Division (CoED) is a division of the American Society for Engineering Education (ASEE). The purpose of ASEE is the advancement of education in all of its functions which pertain to engineering and allied branches of science and technology, including the process of teaching and learning, counseling, research, extension services, and public relations.

The purposes of CoED are identical with those of ASEE but with special emphasis on the following.

- **To provide a medium of exchange for innovative concepts and experience-proven applications of analog, digital, and hybrid computers and other computational methods and devices in education.**
- **To develop, test, and publish research processed curricula for analog, digital, and hybrid computer instruction for student and teacher development at all educational levels.**
- **To contribute to the general knowledge of its membership in the areas of analog, digital, and hybrid computation.**
- **To broaden, where beneficial, the uses of analog, digital, and hybrid computational technologies by educators, students, and educational institutions.**

General Information About CoED

CoED is a division of ASEE, the American Society for Engineering Education. CoED sponsors a number of sessions at each ASEE Annual Conference. Papers presented at these sessions may be published in the Annual Conference Proceedings.

CoED also publishes a quarterly journal, the Computers in Education Journal. CoED Officers are elected for two-year terms and usually follow a chain of succession terminating with the Chair.

CoED also presents a number of awards each year. These awards involve certificates and cash prizes. Some awards are for outstanding papers published in the CoED Journal while others are for outstanding papers presented at the ASEE Annual Conference.

FRONTPIECE

The *Computers in Education Journal* is published by the Northeast Consortium for Engineering Education on behalf of the Computers in Education Division (CoED) of the American Society for Engineering Education (ASEE). The purpose of ASEE is the advancement of education in all of its functions which pertain to engineering and allied branches of science and technology, including the processes of teaching and learning, counseling, research, extension services and public relations. ASEE Headquarters is 1818 N Street, N.W., Suite 600, Washington, DC 20036.

The purposes of CoED are identical with those of ASEE but with special emphasis on the following: a) To provide a medium of exchange for innovative concepts and experience-proven applications of analog, digital, and hybrid computers and other computational methods and devices in education. b) To develop, test, and publish research processed curricula for analog, digital, and hybrid computer instruction for student and teacher development at all educational levels. c) To contribute to the general knowledge of its membership in the areas of analog, digital, and hybrid computation. d) To broaden, where beneficial, the uses of analog, digital, and hybrid computational technologies by educators, students, and educational institutions.

CoED OFFICERS AND DIRECTORS

INFORMATION FOR AUTHORS

The *Computers in Education Journal* contains papers which are relevant to analog, hybrid and digital computation in education. The educational value of the papers published in the *Computers in Education Journal* take precedence over their originality or technical subtlety. Usefulness to educators and their students is the principal criterion for suitability. The inclusion of illustrations, on disk, such as circuit diagrams and computer result curves is recommended.

Authors are invited to submit manuscripts by sending them in duplicate with disks to the *Journal* or e-mailing them to ed-pub@crosslink.net. The review of submitted manuscripts is generally completed within two months after receipt. Papers presented at CoED sessions and seminars will be considered *de facto* as submitted for publication in the *Journal* after their presentation and are subject to the same review procedures as other papers. Prior to publication they will have to be reformatted by the author(s) to meet format guidelines. These detailed guidelines are available on the ASEE Web site along with *Journal* articles.

Manuscripts should be prepared in typewritten form. Disks/e-mail should be compatible with Microsoft Word. Editing marks, if any, should be in standard symbols and clearly legible. Drawings, diagrams, figures should be submitted on disk as incorporated into manuscript text. Printer's proofs of finalized form will be furnished to the author for approval prior to printing. Authors will be requested to pay a nominal page charge upon acceptance of the paper for publication. Detailed information for authors can be found at:
httpt://www.asee.org/publications/divisions/upload/CoEd-Detailed-Information-for-Authors.pdf.

ABOUT THE *JOURNAL*

The *Computers in Education Journal* serves high school, junior college, college and university engineering, mathematics and science faculties who wish to improve the quality of instruction through the use of analog, hybrid and digital computers. The *Journal* assumes no responsibility for the statements and opinions advanced by contributors; the views expressed are those of the authors and do not necessarily represent positions of CoED or the publisher.

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NEWSLETTER

ANNOUNCEMENT OF YEAR 2008 CoED AWARDS/PRIZES WINNERS

CoED AWARDS/PRIZES

THE HARDEN-SIMONS PRIZE

The HARDEN-SIMONS PRIZE is an annual award for the outstanding *Computers in Education Journal* paper on computational methods and is to commemorate the unselfish contributions of Drs. Harden and Simons to CoED.

Dr. Richard C. Harden, PE, received the BME, BEE, MSE and Ph.D. degrees from University of Florida in 1944, 1956, 1957 and 1961 respectively. A WW II Naval Officer and a USNOTS guidance missile range engineer from 1944-50, he was Chief Engineer at AFMTC, FL from 1950-55. He was a University of Missouri at Rolla Electrical Engineering professor from 1961-67 and Director and Electrical Engineering professor of University of Florida Graduate Engineering Education System (GENESYS) from 1967-72. From 1972-87, he was Electrical Engineering professor and Director of the University of Central Florida South Orlando Campus and until his death, was Professor and Director Emeritus. He authored 100 technical papers, and was a member of Eta Kappa Nu, Sigma Zi, Tau Beta Pi, IEEE, ASEE, SES, NSPE and FES. His honors included Teacher of the Year at UCF and UMR, and the John A. Curtis Lecture Award.

Dr. Fred O. Simons, Jr. received his BSEE degree in 1960 from Mississippi State University and the MS and Ph.D. degrees from the University of Florida in 1962 and 1965. He was a faculty member at Mississippi State University, University of Florida, University of Central Florida, and the FAMU/FSU College of Engineering. He was Professor of Electrical Engineering from 1977 to 2004, Director of a Navy Laboratory (1977-78), Chairman of FAMU/FSU (1987-88), Director of FEEDS at FAMU/FSU from 1985 to 2004, and consultant with several industries. He has authored 100+ papers and is a member of Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, IEEE, SCS, FES and ASEE. His honors include National Schlumberger Scholarships and Ford Foundation Fellowship Awards, Engineering Teacher of the Year at UCF, John A. Curtis Lecture Award.

The HARDEN-SIMONS PRIZE for year 2008 consists of a Certificate and a cash award of $400 to Jonathan Hill, Hisham Alnajjar and Saeid Moslehpour of the University of Hartford for their paper entitled, "Educational Discrete Time Signal Processing Toolkit", published in the April – June issue.

Previous recipients of the HARDEN-SIMONS PRIZE are:

(2007) Essaid Bouktache
(2006) Ann-Marie Flynn, Mohammad H.N. Naraghi
(2005) Carlos E. Orozco
(2004) Tariqul Haque, Michael Urbaniak
(2003) John Nydahl, Nance Peck and Scott Morton
(2002) Bruce A. Harvey, Rodney G. Roberts
(2001) Gopal B. Reddy
(2000) John Nydahl,Nancy Peck
(1999) Alireza Rahrooh,Walter Buchanan
(1998) Heidar A. Malki, Guanrong Chen, Shengyi Hou, and Dennis I. Merino, Edgar N. Reyes, and Carl Steidley
(1997) Alireza Rahrooh
(1996) Stephen M. Williams, Robert W. Ashton, and Mark R. Kipps
(1995) Scott van Tonningen
(1994) Alireza Rahrooh and Omid Ansary
(1993) Alireza Rahrooh
(1992) Mohammed Dadfar
(1991) Mohammad H.N. Tabrizi
(1990) Juan Carlos Olabe Basogain
(1989) Raymond G. Jacquot
(1988) George A. Melhem and Bernard M. Goodwin; C.H. Treat
(1987) James A. Harbach, Raymond G. Jacquot, and John W. Steadman
(1986) Raymond G. Jacquot and John W. Steadman
(1985) Raymond G. Jacquot, John W. Steadman, and C. Norman Rhodine.

THE MERL K. MILLER AWARD

The MERL K. MILLER AWARD is an annual prize for the outstanding *Computers in Education Journal* paper on teaching/instructional methods and is to commemorate the contributions and dedication of Merl K. Miller to CoED.

Born in Burns, Wyoming, Merl Miller graduated from the University of Wyoming with a Bachelor of Science degree in Engineering. In 1969, Merl Miller entered the book publishing business at Prentice Hall. Starting as a sales representative, he rapidly climbed to the position of Editor. In 1973, West Publishers was his next step in publishing, before he founded Matrix Publishers, Inc. in 1975. Matrix Publishers, Inc., which became well known for their microcomputer and engineering textbooks, was established because Merl recognized early the growing need for books on microcomputers. Merl Miller became an ASEE member in 1971 and served CoED in various capacities including Vice-President for Industrial Relations. In 1977 Merl Miller formed *dilithium* Press Ltd., a microcomputer book and software publishing house and has authored a large number of books on the subject of microcomputers.

The MERL K. MILLER AWARD for year 2008 consists of a Certificate and a cash prize of $400 to J.C. La Combe, A.M. B Vollstedt and E.L. Wang of the University of Nevada – Reno, for their paper entitled, "Teaching Structured Programming Using Lego Programmable Bricks", published in the April – June issue.

Previous recipients of the MERL K. MILLER AWARD are:

(2006) Owen G. Thorp III, Richard T. O'Brien, Jr.
(2005) John K. Estell
(2004) Richard Layton
(2002) Barbara Bratzel, Martha N. Cyr and Ben Erwin
(2001) Bradley E. Bishop
(2000) R.E. Link, S.M. Miner
(1998) John Watkins, George Piper, E. Eugene Mitchell, and Kevin Wedeward k
(1997) Melvin S. Garelick
(1996) C. Lin, R.K. Romick-Allen, L. Youn, and C. He
(1995) Melvin S. Garelick
(1994) Edward Lumsdaine and Wen J. Wu
(1993) M.S. Garelick; Thomas I. Hemmin Mohammed A. Zahraee, and Gregory Neff
(1992) Robert L. Norton
(1991) Herb Treat
(1990) Alan Wassyng, Samuel Sharp, and Karl Smith
(1989) Maurice F. Aburdene
(1988) David L. Whitman and Ronald E. Terry
(1987) Holly K. Ault and Ronald R. Biederman
(1986) Robert L. Norton
(1985) Leon W. Couch and Charles V. Shaffer.

THE RAY H. SPIESS AWARD

The RAY H. SPIESS AWARD is an annual prize for the outstanding *Computers in Education Journal* paper on hybrid analog/digital computers/computation and is to commemorate the contributions of Ray H. Spiess and Comdyna, Inc., to the development of CoED.

Born in Cincinnati, Ohio, Ray H. Spiess graduated from Purdue University with a Bachelor of Science in Mechanical Engineering. In 1968, he founded Comdyna, Inc., Barrington, Illinois, a manufacturer of analog/hybrid computing systems. He is credited with the following designs: The GP-6 analog computer, the first general purpose analog computer to utilize the integrated circuit operational amplifier; The Microhybrid I, the first microprocessor based hybrid computing system; Micropatch, a microcomputer controlled electronically patched analog computer. Through Comdyna, Inc., he was one of the original sponsors of CoED.

There was no 2008 winner of the RAY H. SPIESS AWARD.

Previous recipients of the RAY H. SPIESS AWARD are:

(1990) Nicholas M. Karayanakis
(1988) Nicholas M. Karayanakis
(1987) George E. Abdo
(1986) Samuel J. Lynch
(1985) Raymond G. Jacquot and John W. Steadman.

THE EAI AWARD

The EAI AWARD is an annual prize for the outstanding *Computers in Education Journal* paper on analog computers/computation and is to commemorate the contributions of EAI (Electronic Associates, Inc.) to the development of CoED.

Electronics Associates, Inc. was founded in 1945 as a leading designer and manufacturer of computer-based simulation systems for design, analysis and training, and data acquisition and control systems. EAI, with products marketed worldwide to the aerospace, electric power and other energy related industries, was the original sponsor of CoED and its predecessor organizations headquartered in West Long Branch, New Jersey.

There was no 2008 winner of the EAI AWARD.

Previous recipients of the EAI AWARD are:

(1997) Nicholas M. Karayanakis
(1989) Edgar Conley and Kenneth Kokser
(1985) Nicholas M. Karayanakis.

JOHN A. CURTIS LECTURE AWARD

The John A. Curtis Lecture Award was established by CoED in 1974 as a prize for the best paper presented at the CoED sessions of the ASEE Annual Conference. The year 2008 award consists of a Certificate and a cash prize of $300 to Robert Avanzato of Pennsylvania State University - Abington , for his paper entitled, " Suburban Outdoor Challenge for Autonomous Mobile Robots ".

John Avery Curtis (1909-1988) was born in Brooklyn, New York and received the BA from Yale in 1930. He held public relations, marketing, and executive positions in the entertainment, publishing, communications, and electronics industries and served as vice president and general manager of the marketing division of Electronics Associates Inc. from 1962 to 1968. He was the founding president of a non-profit educational communications network, Center for Excellence, Inc., in Williamsburg, Virginia. He served as Executive Secretary of CoED and its predecessor organizations from 1968 through 1974 and was credited as the key figure in the formation of CoED as part of ASEE. His listings included Who's Who in the South and Southwest.

Previous recipients of the JOHN A. CURTIS LECTURE AWARD are:

(2007) Brianno Coller
(2006) Naveen Nattam, Kermin Martinex-Hernandez, Doug Danforth, Steve Emberton, Ryan Pedela, Eugene Elkin, Kellen Maicher, Carlos Morales and Gabriela Weaver
(2005) Thad B. Welch, Cameron Wright and Mike Morrow
(2004) J. W. Bruce
(2003) Andrew Gavrin, Jeff Watt, Kathleen Marrs and Robert Blake
(2002) John Nestor
(2001) Geroge Piper, John Watkins, Svetlana Avramov and Carl Wick
(2000) Brian Stone, Sunill Hiranniah, Nathan Scott and Mohamed Manna
(1999) Francois Michaud
(1998) Cameron H. G. Wright and Thad B. Welch
(1997) John Watkins, George Piper, Kevin Wedeward, and E. Eugene Mitchell
(1996) Jerry C. Hamann
(1995) Kurt Gramolll
(1994) John K. Estell
(1993) Robert I. Avanzato
(1992) Richard J. Reid
(1991) Kyran D. Mish, Stephen P. Hurst, and T. Joseph Holland
(1990) John R. Zeller
(1989) C. Bruce Myers and Tim Grady
(1988) William L. Cleghorn
(1987) Val Watson
(1986) George Y. Jumper, Jr. and John J. Titus
(1985) Glen A. Afflerbach, Ronald E. Terry, and David L. Whitman
(1984) Robert L. Norton
(1983) Albert L. Riemenschneider and Michael J. Batchelder
(1982) Richard C. Harden and Fred O. Simons, Jr.
(1981) Trevor Mudge
(1980) John W. Steadman, Raymond G. Jacquot, and Mark N. Hepworth
(1979) Dean K. Frederick and Gary L. Waag
(1978) C. Norman Kerr
(1977) James L. Lubkin
(1976) Nicholas Perone
(1975) R.V. Houska, M.R. Buric, and S.J. Kahn.

WOODY EVERETT AWARD

The Woody Everett Award was established by CoED in 1988 for the best paper/presentation/ demonstration at the CoED Poster Session of the ASEE Annual Conference. There was no 2008 winner of the WOODY EVERETT AWARD.

Woodrow W. Everett, Jr., was born in Newton, Mississippi on October 11, 1937, and graduated from Murphy High School in Mobile, Alabama in 1955. He received the BEE degree (1959) from the George Washington University and the MS degree (1965) and the Ph.D. degree (1968) from Cornell University. He is chairman of the Northeast Consortium for Engineering Education (NCEE). His publications include six books in electronics, engineering education, and management and his published papers are in electromagnetics and electronic systems. He was designated Fellow (1976) and Life Fellow (2003) by the Institute of Electrical and Electronics Engineers. He was designated Life Member by the Air Force Association in 1984 and Life Member of the Reserve Officers Association in 1996. He has been a member of ASEE since 1962 with active participation in CoED (and its predecessor organizations); he served as CoED Chairman from 1986 to 1988 and since 1988 has served as CoED Managing Director with oversight of CoED publications. His military service was in the U.S. Air Force; he is a retired colonel. He received the Engineering Alumni Achievement Award from The George Washington University at its 175th Anniversity Commencement in 1996. The Everett Endowed Chair in the Northeast Consortium for Engineering Education (NCEE) provides infrastructure support to NCEE. The Everett Scholarship Fund in the United Methodist Foundation provides financial assistance to selected entering undergraduates at accredited Colleges and Universities. The Woodrow W. Everett, Jr. SCEEE Development Fund Trust provides initial research funding to electrical and computer engineering faculty members with less than five years faculty experience via annual proposal competition at southeastern U.S.A. Institutions. His listings include: Who's Who in America, The American Scientific Registry, Who's Who in Industry and Finance, Dictionary of International Biography, Who's Who in the South and Southwest, Men of Achievement, Who's Who in the World, Who's Who in Technology, Who's Who in Engineering, Notable Americans, Personalities of America, Community Leaders of America, International Who's Who in Engineering, Personalities of the South, Who's Who in the East, Who's Who in Florida, Personalities of the Americas, The Directory of Distinguished Americans, Who's Who in American Education, The International Directory of Distinguished Leadership, American Men and Women of Science.

Previous recipients of the WOODY EVERETT AWARD (identified as the CoED Poster Session Award prior to 1989) are:

(2006) James Reising
(2005) Igor Verner
(2004) Nicholas Krouglicof
(2003) William Cleghorn and Nikolai Dechev
(2002) Beth Kolko and Linda Whan
(2001) Robert Avanzato
(2000) Carl Wick and Kenneth Knowles
(1999) Wayne Padgett
(1998) Devdas Pai, Ajit Kelkar, Richard A. Layton, Mark Schulz, DeRome Dunn, Samuel Owusu Ofori and Abjijit Duraphe
(1997) James P. Blanchard
(1996) Essaid Bouktache, Chandra R. Sekhar and Omer Farook
(1995) Ronald G. Forsythe and Michael L. Mavrovouniotis
(1993) L.D. Thede
(1992) Peter C.M. Burton
(1991) J.E.D. Geleyn and Robert J. Ferguson
(1990) Peter C.M. Burton
(1989) W. J. King and S.K. Howell
(1988) Helen Kuznetsov
(1987) Richard R. Thomas, Donald A. Smith and William C. Porter
(1986) Arthur Johnson
(1985) J. Jeswiet
(1984) David B. Meredith
(1983) David L. Huggins and Roy E. Myers.

THE FINANCIAL CRISIS OF 2008

Mark Kasdorf
Boston University School of Law

Abstract

Events in the financial markets over the past 14 months have had a significant impact on university faculty and programs: endowments have decreased; student loans have been impaired; research and program support have decreased; retirement funds have been affected; and a high degree of uncertainty has permeated through nearly every budgetary decision made at universities. This paper examines some of the root causes of the financial situation, attempting to provide a history of how we have arrived at today and to gain some insight at what tomorrow will hold.

Introduction

Events over the past 15 months have had startling effects on nearly every facet of society. University faculty and students have not been spared from fallout of the financial market crisis. In the 2007 fiscal year, college endowments had an aggregate value of $411.1 billion.[1] As events play out, by the end of fiscal year 2009, this amount is likely to drop by at least 30% to $287.77 billion. As 2009 begins, all aspects of university life will be affected: funding for laboratory facilities; grants for both students and faculty; state and federal aid for student tuition; availability of student loans; faculty and staff salaries and retirement plans; funding for non essentials such as athletics and drama programs; and nearly any other aspect of university life that requires some form of capital contribution to support. This paper examines some of the contributing factors and events leading up to the current situation in the financial markets as well as presenting some suggestions as to what the future might hold.

As early as March 2007, the first headlines began sporting the term "Subprime Crisis".[1] On October 9, 2007, the Dow Jones Industrial Average hit an all-time high of 14,164.53.[2] On December 4, 2008, the market had dropped over 40% amid extraordinarily volatile trading,[3] the term "Subprime Crisis" has graced headlines in the *Wall Street Journal* 544 times since March 2007[4], and the subprime crisis has produced new headlines such as "Subprime Meltdown" and "Global Credit Crunch." These turbulent times beg the questions: How did we get here and where are we going?

A variety of factors have led to the current situation, but the focus of this paper will be securitization and the magic of tranching[5]. Through a combination of political pressure and Wall Street's[6] constant drive to maximize profits within the regulatory framework provided by the government, securitization has become increasingly convoluted. No longer is securitization as simple as bundling a number of like instruments and selling the newly created 'security' in order to diversify risk. Securitization has been complicated by by such contrivances as credit default swaps (CDS), structured investment vehicles (SIV),[7] collateralized debt obligations (CDO), and collateralized debt obligations squared (CDO^2)[8].

This paper will begin by providing the reader with a brief history of home ownership in order to examine some of the base motivations in government policy that led to the current situation. The next several sections will provide an understanding of some of the complex financial instruments that the financial services industry has developed over the past 15 years. In the penultimate sections, the paper will examine exactly how the current situation evolved from a stable market into a financial meltdown where the likes of AIG effectively have been nationalized and 125-year old investment banks have disappeared. In the final section I will present a new structure of 'incentives'[9] to avoid similar breakdowns in the market going forward. Ultimately my aim is to demonstrate that *more* regulation is not necessarily the answer so much as the *right* regulation is.

Homeownership

History

The Crisis[10] has deep roots in the mortgage industry. Although the majority of this paper will focus on securitization, some history behind political and tax pressure effects on the mortgage industry is necessary for a proper understanding. The U.S.'s stance on debt versus equity, along with an understanding of the Community Reinvestment Act (CRA) and Fannie Mae/Freddie Mac, are all factors in the current situation.

Tax Law

Tax law plays an integral part in nearly all major financial decisions. The Tax Reform Action of 1986 eliminated the standard deductibility of interest payments on all debt, but allowed for the narrower deduction on interest up to $1,000,000 in mortgage debt and $100,000 in home equity debt.[11] In addition to this, taxpayers are allowed a deduction of $250,000 ($500,000 for married couples) on capital gains from the sale of residential property if the owner used the property as their primary residence for two out of the preceding five years.[12] These tax policies create incentives for both home ownership, and more specifically, home ownership via debt.

Fannie Mae and Freddie Mac

In 1939 Fannie Mae was born[13] with Freddie Mac following in 1970.[14] Fannie Mae and Freddie Mac are government-sponsored privately-owned institutions known as "Government Sponsored Enterprises" (GSE). The President is able to appoint five of the eighteen directors of each board.[15] Public shareholders elect the rest. The Office of Federal Housing Enterprise Oversight and the U.S. Department of Housing and Urban Development regulate both entities.[16] As a final regulatory measure, the Department of Treasury must approve any issuance of debt.[17]

Contrary to popular belief, Fannie Mae and Freddie Mac are not lending institutions. Instead, these entities provide liquidity to loan originators by taking mortgages off their books, bundling and securitizing them, and selling the securities. Fannie Mae and Freddy Mac are able to do this through their special government-sponsored status that exempts them from state taxes[18] and federal securities laws[19], offers them a line of credit from the U.S. Treasury,[20] and allows them the power to issue securities through the Federal Reserve electronic book-entry system.[21] Although Fannie Mae and Freddy Mac are not government agencies, and hence are not backed by the full faith and credit of the U.S. government, there has been a perception that the U.S. would honor their obligations in the event of financial failure.[22] This allowed them to obtain financing on terms superior to other entities in the financial industry.

Without Fannie Mae and Freddie Mac, lending within a given geographial region would freeze once that region became saturated with mortgages. By creating liquidity through securitization, Fannie Mae and Freddie Mac have allowed Americans with good credit to obtain mortgages for the last 50 years. In addition to this liquidity, banks seek to offload and/or trade loans through securitization in order to minimize excess exposure to any single market.[23]

The Community Reinvestment Act

The Community Reinvestment Act (CRA) was enacted in 1977.[24] The purpose of the act was to require depository institutions to meet the lending needs of the entire surrounding community.[25] The original law did not require high-risk lending and was extremely subjective in its enforcement. Regulations merely required that lending institutions periodically be reviewed for fair lending practices and that such records be taken into account when applying for deposit facilities.[26]

The Changes of 1999

In 1999 a variety of forces materialized to begin pressuring Fannie Mae to expand subprime credit facilities.[27] First, the Clinton administration exerted political pressure to expand mortgage offerings to low-income individuals with poor credit ratings. Second, Fannie Mae shareholders sought higher growth rates and returns than could be achieved through traditional lending. Third, banks themselves began pressing Fannie Mae to help with subprime borrowers.[28]

Finally, the Gramm-Leach-Bliley Act was passed.[29] In 1933 the Glass-Steagall Act was passed with the primary purpose of separating commercial banks from underwriters.[30] The co-mingling of these two entities was seen as having been a major cause of the Great Depression. The Gramm-Leach-Bliley Act of 1999 was a monumental piece of legislation that reversed the Glass-Steagall Act, allowing commercial banks and securities underwriters to merge. In a move not directly related to expanding subprime lending, the Clinton Administration insisted that approval of any merger between two institutions be contingent upon approval of the regulatory bodies responsible for the CRA.[31] This bolstered the regulatory power of the CRA by creating a new consequence for banks that did not abide by the terms of the CRA.[32]

Even in 1999, people saw the potential dangers inherent in such measures. In the Sept. 30, 1999 *New York Times* article "Fannie Mae Eases Credit to Aid Mortgage Lending", Steven Holmes wrote:

> In moving, even tentatively, into [subprime lending], Fannie Mae is taking on significantly more risk, which may not pose any difficulties during flush economic times. But the government-subsidized corporation may run into trouble in an economic downturn, prompting a government rescue similar to that of the savings and loan industry in the 1980's.

Four years later, in 2003, the *New York Times* again commented on Fannie Mae's exposure and the unusually high level of risk that they had taken on.[33]

Historic Conclusions

Although it cannot be said that the tax system, CRA, or Fannie Mae directly caused the current financial crisis, it is important to understand how many of these historic events have impacted and shaped where we are today. The U.S. economy has been promoting home ownership as a means of wealth generation for decades. Debt has been favored over equity and has risen sharply over the years. Total mortgage debt in the U.S. as of Q2 2008 is estimated at $14.4 trillion.[34] As of March 2008, total home equity in the U.S. was estimated at $587 billion.

The entire mortgage market was supported by just 4.07% equity.[35] Since March this number has fallen as home values fell and equity disappeared.

There are a variety of excellent reasons for the above policies, and it is by no means the purpose of this paper to imply they are the cause of the current crisis. The above considerations are merely provided as a backdrop to the events leading up to the collapse that began in August 2007 and to help the reader understand how things began to unravel.

The Mechanics of Securitization

Definition of Securitization

Securitization is:

> The sale of equity or debt instruments, representing ownership interests in, or secured by, a segregated, income-producing asset or pool of assets, in a transaction structured to reduce or reallocate certain risks inherent in owning or lending against the underlying assets and to ensure that such interests are more readily marketable, and thus more liquid

than ownership interests in and loans against the underlying assets.[36]

In simpler terms, securitization is converting third party obligations into tradable securities.

Another term for securitization is "structured financing."[37] In general, structured financing is securitization when a large corporate borrower uses securitization as a financing tool. Such entities are able to securitize both their obligations and financial assets.[38]

The Birth of Securitization

Modern securitization began in the mid 1970s with the birth of securitization of loans by participation(LP).[39] LPs were used to securitize large loans during this time and is distinguishable from syndication among lenders.[40] Banks were willing to sell LPs for many of the reasons enumerated in the preceding section and, most notably, to generate fee income and promote liquidity.[41] Until 1999, LPs were unique in that they were not subject to the legal limitations on securities' holdings, thus allowing banks to diversify their holdings in ways not otherwise allowed. This changed in 1999 with the Gramm-Leach-Bliley Act; since then, LPs have lost their primary advantage.[42]

Securitization by pooling was also contrived in the 1970s. The practice began with the pooling of mortgage loans.[43] These loans are pooled into special purpose vehicles (SPV) which distributes the securities issued by these pools.[44] The creation of secondary markets for these securities was quick to follow.

As early as 1973, the government created the Student Loan Marketing Association (SLMA, or Sallie Mae) to aid in securitizing student loans.[45] Until then, banks were unable to securitize such loans without aid from the government.[46] Although Sallie Mae still exists, through credit swaps banks are now able to effectively securitize such loans without aid from the government agency.

The Growth of Securitization

The growth trajectory of securitization has been tremendous. In 1989, the market for mortgage-backed securities had reached approximately $900 billion.[47] By Q2 2008, outstanding mortgage-backed securities (MBS) had reached $6.2 trillion in total value,[48] making it the second largest fixed income market behind U.S. Treasuries.[49] Asset-Backed Securities (ABS) had reached an aggregate outstanding balance of nearly $2.5 trillion as of Q2 2008.[50]

Nearly anything that can be securitized has been securitized. Initially, securitization expanded from mortgage loans to auto and truck loans.[51] From there, the flood gates opened and, over the next several decades, the number of different assets that were securitized exploded to include health care and pharmaceutical receivables;[52] license and franchise fee receivables; airline ticket, hotel, and other travel receivables;[53] tax receivables;[54] trade credits;[55] equipment and automobile leases;[56] taxicab medallions;[57] computer leases;[58] municipal leases;[59] bad debts and defaults resulting from credit cards and junk bonds;[60] cosmetic surgery receivables;[61] loans made by the U.S. Government;[62] royalties from performing artists record sales;[63] natural resource assets;[64] mutual fund shares;[65] athletic venue revenues;[66] software financing obligations[67]; third world loans.[68] This list is not exhaustive; however, it does demonstrate how pervasive securitization has become in the U.S. economy.

The Mechanics of Securitization

The precise structure of a securitization transaction can vary widely, but all such transactions have five basic steps: (1) A loan is made (2) the loan is transferred to an SPV (3) credit enhancements are provided [69] (4) the securities are distributed by the SPV (5) a secondary market for these securities is formed.[70]

Once a loan originator (often a bank) has made a loan, the loan becomes an asset. Thus, a bank might make one hundred $200,000 loans that amortize fully over 30 years at a 6% rate of interest. Each of these loans will generate payments (principal and interest) totaling roughly $14,500 per annum for 30 years. From here, these loans are transferred to an SPV.[71] The SPV serves a primary purpose of protecting the investors of the securities, alienating the assets in the SPV from any of the liabilities of the originator [72]. The SPV has no liabilities other than to investors.[73] Thus, the funds from the securities sales flow back up to the bank and, even if the bank enters bankruptcy, the pooled assets in the SPV that have been securitized are safe from the creditors of the originator.

After the assets are placed in the SPV, they are securitized. In our example, the one hundred $200,000 loans might be securitized into 1000 'shares' that each represents a stream of payments of $1,450 per annum for 30 years. Finally, these securities are sold to investors. The assets (loans) stay in the SPV, and payments are distributed to the investors. The primary risk to investors involves the integrity of the stream of payments from the securities and, hence, the SPV; in our example the payments come from one hundred individual mortgages. In most cases, mortgages are considered a safe investment because of the underlying security's value. It is this very belief that sets the stage for difficulties that have recently beset the markets.[74]

The Rules and Regulations Behind Securitization

Securitization is regulated by a patchwork of laws. The making of loans and creation of financial assets is governed by laws concerning lending. Establishing the necessary SPVs requires use of corporate, partnership, trust, and other sources of law that govern establishment of such entities. The Uniform Commercial Code and its counterpart in each state govern the transfer of the financial assets. Securities laws govern distribution of securities after they have been bundled.[75]

A large part of this regulatory framework consists of disclosure regulations.[76] The purpose of the various laws is not to restrict what can be securitized but to make sure that proper disclosure is made at each step of the process so that investors are aware of what they are investing in and the risks relative to other investments. In 1986, an Economist article published a popular Wall Street saying. "If it's gradable; it's tradable."[77] As long as sufficient data were provided to the ratings agencies, the agencies were willing and able to provide a rating for a new security. Nearly any asset could be securitized at a relatively low cost.[78]

The Collateralized Debt Obligation (CDO)

History

The infamous Wall Street firm Drexel Burnham Lambert Inc. created the first CDO in 1987. The transaction was for Imperial Savings Association, which later became insolvent, and was eventually taken over by the Resolution Trust Corporation in 1990.[79] Growth of the CDO industry over the next 14 years was relatively slow until the creation of the Gaussian Copula Model by David X. Li in 2001.[80] Before 2001, the aggregate outstanding CDO obligations totaled about $280 million. Between 2001 and 2004 this number grew to over $1.5 trillion.[81] Current estimates place it at roughly $2.5 trillion.[82]

Definition

CDO's are similar to MBSs in that they are both bundles of, often illiquid, assets that are pooled together and securitized for distribution in a secondary market. In general, MBSs, along with many other types of assets provide the collateral within a CDO. Depending on the assets backing the instrument, a variety of different "flavors" of CDOs exist, including Collateralized Loan Obligations (CLO),[83] Collateralized Bond Obligations (CBO),[84] and Collateralized Mortgage Obligations (CMO).[85]

CDO Mechanics

The most interesting feature of a CDO[86] is its ability to offer multiple 'tranches' of securities. A tranche is Wall Street jargon for 'level.' By tranching its securities, a CDO is able to offer multiple securities with different credit ratings comprised of the same underlying assets.[87] The purpose of such a structure is to spread the underlying credit risk of the assets among investors in a manner proportional to the amount of risk they are willing to assume. A typical CDO capital structure might contain four tiers of debt: (1) AAA [88] rated tranche comprising 65% to 85% of the CDO; (2) AA rated tranche comprising 5% to 15%; (3) BBB rated tranche comprising 5% to 10% of the capital structure; (4) BB rated tranche comprising 5% to 10% of the CDO; and (4) an unrated 'equity' tranche [89] comprising 3% to 12% of the capital structure.[90] In general, insurance companies and banks invest in the AAA and AA tranches, and insurance companies, hedge funds, and high net worth individuals seeking higher yields invest in the remaining tranches.[91] Each tranche is paid interest from the cash flows of the underlying assets in order of seniority.

Going back to our original example, suppose a CMO was comprised of one hundred $200,000 mortgages at 10% per annum. Rather than each tranche receiving a 10% coupon, the AAA might receive a coupon for 7%, the AA for 7.75%, the BBB for 13%, the BB for 15%, and an "equity tranche"[92] for 18%.[93] If the cash flows were to shrink, the various tranches would bear the associated losses in order of seniority. Equity would lose their coupons first, BB second, etc. Through this structure, a variety of investors with different levels of risk aversion are able to invest in securities that meet their needs.

To provide an even simpler example, imagine 10 people are sitting at a table and rolling dice. Anything above one is a winning roll. Each player puts in $1 each roll. The most risk averse player wins $1.06 if a single die rolls two or higher. The next most risk averse player wins $1.08 if just two dice roll two or above. The player willing to bear the greatest risk will win $1.20 if at least eight of the dice come up two or higher. In this way, mathematically, the chances of the first player not winning are extremely low.[94] Theoretically, in order for the AAA debt holders to lose their money, unprecedented drops in the value of the underlying CDO assets would have to occur.

The above structure has no built-in limits as to how complex a CDO can become or how many tranches can be offered. For example, in 2004, Axa Investment Managers launched the Aria CDO.[95] The Aria CDO referenced a pool of 140 corporate names, was divided into 28 tranches in five currencies – Swiss francs, sterling, dollars, euro and yen – and incorporated fixed, floating, and inflation-linked tranches.[96]

CDO Intricacies

The above structure, although complex, is relatively understandable. A group of cash assets are bundled and securitized. The security is then segmented to allocate different levels of risk to those investors with the corresponding appetites for such risk. CDOs are similar to mutual funds in that there are a variety of different types with different strategies. In mutual funds there are numerous different criteria that define a given fund. For example: domestic or international; growth or value; small, medium, or large cap. These different criteria can be mixed and matched in a variety of ways to build a fund strategy. As the popularity of CDO investments increased, ever-increasing layers of complexity convoluted this structure. This section will briefly observe some of these complexities and attempt to offer a fuller understanding of the differences between various CDOs.

Source of Funds/Rating - Cash Flow Versus Market Value Model

The primary method of valuing a CDO is through its rating. Two different methods of rating the inherent credit risk in a CDO have dominated throughout the decade. The method used is generally premised on the underlying strategy of the fund. The cash flow model focuses on the creditworthiness of the underlying assets as well as the sufficiency and predictability of the cash flows.[97] In our mortgage example, the rating agency might look at the underlying value of homes on which the mortgages were taken, the degree of total leverage on these homes, and the ability of the mortgagor to continue to make payments.[98] CDOs using this model generally seek to maximize returns by carefully managing the underlying assets within the portfolio.

The market value model looks to the value of the underlying assets rather than the strength of the cash flows being generated. Under this model, the price sensitivity of the asset is determined and used to create a trigger, at which point the asset could still be liquidated with enough proceeds to pay the various contingencies of the CDO.[99] Using this model, the value of the underlying assets should be monitored frequently in order to reassess risk and accurately price the securities. In the mortgage example, assuming the bundled mortgages are all senior notes on the properties, a trigger point of $220,000 might be set. As the market value of the mortgages dropped below various triggers, the ratings for the securities could be adjusted accordingly. CDOs using this model are generally actively managed, and the collateral turns over more often in an attempt to keep the underlying risk of the portfolio consistent.

Funding – Cash Verses Synthetic CDO

As discussed, CDOs generally take existing income producing assets and package them into securities. In this respect, we have thus far considered cash CDOs. Cash CDOs use real assets as collateral. A typical cash CDO is one backed by mortgage obligations. Mortgages are hard assets with homes as collateral. In the event of a default, the houses can be foreclosed upon and the proceeds used to mitigate losses in the CDO.

Standing in contrast, synthetically funded CDOs do not own the underlying assets but seek credit exposure through the secondary market of credit default swaps (CDS).[100] Thus, synthetic CDOs can simulate an identical risk exposure to a cash CDO without actually purchasing or owning any assets.[101] There are several advantages to synthetic CDSs. First, synthetic CDOs can be created much faster than cash CDOs. Purchasing assets takes time, while purchasing CDSs does not. Also, even in the debt filled market of 2006, debt instruments were becoming scarce. By building a synthetic CDO it was not necessary to find actual debt to purchase. Synthetic CDOs have gained in popularity in large part because of the low cost access it gives entities to the bond market when the entities previously had no access.[102]

Motivation – Balance Sheet Versus Arbitrage CDO

CDOs fall into various categories, most generally either balance sheet or arbitrage funds. The comparatively simple balance sheet CDO serves a specific purpose: our mortgage example is a typical balance sheet CDO. A loan originator forms a CDO either to remove mortgages from its balance sheet or in anticipation of doing so.[103] From here, the CDO offers all the advantages that we have discussed in terms of tranching securities and allowing for risk to be spread to those parties willing to take it. The only purpose of a balance sheet CDO is to help banks diversify risk.

Arbitrage funds are considerably more complex. All securitized debt is rated. Such debt falls on one side or another of an arbitrarily drawn line delineating the boundary between investment grade securities and 'junk' bonds. Given the restrictions on many major institutions[104] from holding below investment grade debt, the spread between investment grade and below investment grade debt is often much larger than can be rationalized by the underlying risk. Through the creation of a CDO, $100 million in below investment grade debt can be bundled and securitized in the process discussed above.

Assume that an arbitrage CDO is formed for the purpose of securitizing $100 million in B grade debt from 20 different medium-sized corporations. By bundling and securitizing this debt into an arbitrage CDO, rather than the entire $100 million of debt being rated at a B level, with an effective interest rate of 11%, the debt might be rated according to the scheme set forth earlier. In this way, 65% of the debt might be given a AAA rating[105], with various other tranches bearing the additional risk shed by this portion. Through this process, the effective yield on the entire fund might be just 9%, allowing the CDO manager to take a 1% fee and still provide an interest rate of 10% rather than 11% to the corporations.

The reason this works is that there is a much smaller buying audience for B rated debt because many institutional buyers are unable to purchase below investment grade securities. Thus, demand is lower than it should be and yields are pushed up. By tranching the security, a portion of it can be offered at investment grade, increasing overall demand and lowering effective yield. The principle behind this process is not necessarily flawed, though it is clear that there is a substantial chance for abuse given the complexity of these funds and the difficulty of accurately rating the various tranches. The vast majority of CDOs are arbitrage CDOs.[106]

Single Tranche CDO[107]

A single tranche CDO is structured identically to a normal CDO with the only caveat being that the sponsor of the fund sells only a single tranche. Single Tranche CDOs are almost always synthetic. In these cases, the sponsor holds the vast majority of the portfolio. For example, a hedge fund may approach a loan originator and request a custom CDO to be built for the fund. The hedge fund might specify a return of 9%, desired portfolio composition, tranche size, spread, and target rating. After selling this large tranche, the issuer will retain the rest of the CDO delta hedged[108] within their portfolio.[109]

Single Tranche CDOs offer a variety of advantages to a seller and have been a primary driver in the synthetic CDO industry.[110] In a single tranche CDO, a dealer is able to effectively build a fund and sell a single slice of credit risk to a single buyer. In this way, transaction costs are reduced significantly, and the needs of the two involved parties can be adequately met. Single tranche CDOs provide yet another example of how increasingly complex instruments have allowed an incredible amount of risk to be spread among the system as various organizations are able to select a security that precisely meets their needs.

CDO Regulation

Under the current regulatory framework, CDOs themselves are not regulated; they are merely instruments. Similar to securitization, it is the process of creating a CDO that is regulated. The entire process is nearly identical to the securitization process; CDOs are simply securities that are being tranched. The only added layer of regulation is that each tranche must be separately rated by the ratings agencies.

The CDO^2 and Credit Default Swaps: Spreading Risk Throughout the Market

Our final technical section will examine two relatively complex instruments that were developed recently and played a pivotal role in the market meltdown that is currently unfolding. Currently, both of these instruments are extremely lightly regulated. Given recent events, this is unlikely to remain the case.

One purpose of this paper is to discuss risk. Whenever a lending institution originates a loan, the institution is subject to a 'bundle' of risks, including interest rate-market risk (the risk of unexpected changes in interest rates), liquidity risk (inability to sell an asset), and credit risk (default on the part of the seller).[111] A simple mortgage provides an excellent example of each of these. Assume a 30-year $200,000 mortgage is issued at 10%. A bank has three potential risks associated with this loan: (1) The market rate on deposits (how the bank funds its lending) could unexpectedly rise to 11% (2) the bank could experience a run on its deposits and be forced to sell the loan for substantially less than it is worth do to the instant need for capital (3) the mortgagor could default on the loan.

Credit Default Swaps

Credit default swaps (CDSs) were first engineered in 1987 on Wall Street. From its inception just 21 years ago, the total face value of interest rate and currency derivatives contracts exceeded $200 trillion by the end of 2007![112] Another $17 trillion is currently outstanding in new CDSs.[113] Regulators in the financial services industry were speculating as recently before the "Crisis" as 2006 that CDSs were growing far too fast for any self-regulation system to keep up and that, without outside intervention, banks would be unable to cope with a failure in the system.[114]

The purpose of a CDS is to allow a loan originator to reduce the default risk of a given transaction. In our example of a single $200,000 mortgage, the originator might purchase a three year CDS from another institution for a fee of 1% (the spread) of the total value of the loan per annum. In exchange for this fee, the seller of the CDS agrees to either take over the loan at face value in the event of default, or, more often, pay a sum of money through a third party intermediary to settle the note for the originator. Thus, the originator is effectively purchasing an insurance policy on the debt issued. CDSs are generally written on corporate bonds, and the spread is dictated by the rating of the bond. Payment on a CDS is triggered by some predetermined event such as degradation in credit rating, default on two consecutive payments, etc.[115]

Triggering events can be defined in innovative ways to create a unique risk profile for a lender. For example, if a lender makes a $10 million loan to a corporation and wishes to take on the default risk for the corporation, but hedge against the industry risk, a CDS could be purchased tied to an industry index rather than the stock price of the corporation or its bond rating.[116]

Taken at face value, the CDS seems to be nothing more complex than bond insurance. The driving factor behind the CDS market is that the purchaser of a CDS does not have to be an originator. Anyone can purchase a CDS against any entity if they can find an insurer willing to sell it. Thus, a hedge fund with no financial stake in General Motors (GM) might purchase a CDS against a GM bond on the assumption that GM will be forced to default in the next two years. In this way, CDSs have become less a means of insuring against debt issuance and more a method of hedging against any trade, or even just betting against debt. John Paulson managed to achieve a 598% return in 2007 through a strategy of using CDSs and other derivatives to bet against the housing sector.[117]

Collateralized Debt Obligation^2

CDO^2s combine the entirety of the financial concepts discussed within this paper to create a financial instrument so complicated that very few people in the market have a firm grasp on how they work and how best to value them. Generally speaking, CDO^2s are simply a CDO of CDOs. In a typical CDO^2, a master CDO is set up which purchases only tranches of other CDOs.[118] The senior tranches of this master CDO theoretically have two layers of protection from default. For example, assume an originator creates a CDO^2. This CDO could purchase all BBB tranches of other CDOs. By re-tranching these tranches, the CDO^2 can sell a range of securities from AAA to equity tranches.

There are a variety of difficulties inherent when trying to value CDO^2s and assign a credit rating to their issued securities. One is created by the overlap in the various CDOs that comprise a CDO^2.[119] This overlap is inevitable. When the proliferation of CDOs began its heyday in 2003, there were roughly 400 corporations with liquid securities in the CDS market.[120] In a typical CDO^2, over 1000 companies are referenced, implying that there is a significant amount of overlap within a single CDO^2.[121] The problem with this overlap is that it makes exposure to a given company or industry very difficult to determine and thus makes rating the security difficult. This is one of the many issues that ratings agencies have struggled with for the last ten years as these securities have proliferated. Obviously, the problem is compounded exponentially when CDO^2s are compiled into a CDO^3, etc.

One of the problems that occurred when subprime markets started to turn was the perceived diversification of CDO^2s. Going back to our dice-rolling example, imagine that all ten dice need to roll a one before the senior tranche loses any value. As long as all the players are rolling different dice, there is little chance of any loss. However, if everyone is rolling the same die, suddenly the senior tranche does not have nearly the perceived protection. This is one of the effects of CDO^2s owning tranches from many different CDOs. If the senior tranche in a CDO^2 is safe as long as there are fewer than 8 defaults in the underlying assets and there is a single default, there are no losses. If the defaulting security asset is held by 9 CDOs that make up the CDO^2, then the CDO^2 registers 9 separate defaults due to their high exposure to that security, and this single default triggers losses. This has resulted in an enormous amount of risk filtrating the market with deceiving credit ratings.

The Crisis

On October 16, 2008, *The Economist* proclaimed "2008 marked the end of an era."[122] The article goes on to blame nearly the entire financial disaster on decreased regulation and increased pressure to write subprime loans.[123] John Gutfreund remarked in a recent interview with Michael Lewis that the entire disaster is to blame on greed, "greed of investors and the greed of the bankers."[124] Thousands of people and pundits across the country are crying fraud and demanding that the crooks on Wall Street go to jail.[125] In reality, the crisis was caused by a series of events that, when taken in aggregate, combined to create a market situation that no one could predict.

Subprime Lending

Certainly one of the biggest problems has been the proliferation of subprime lending. In recent days, this problem has been laid at countless different entities' feet including the Republican Party,[126] Democratic Party,[127] lending institutions, and the Federal Reserve.[128] In 2006 and 2007 alone, over $1.2 trillion in new subprime loans were originated. The problem stems from a combination of events over two decades and the fundamental market belief that went horribly wrong: that home values would never fall across the country.

Subprime lending is lending money to people that cannot obtain credit in standard markets at standard market rates. Generally, those borrowing with credit scores lower than a FICO[129] credit score under 600 will be forced to obtain a 'subprime mortgage.'[130] Subprime mortgages fall into one of two sub groups: fixed and adjustable rate (ARM).[131] As of December 2007, just 6.8% of all mortgages were subprime ARMs; yet, these same mortgages comprised 43% of the foreclosures within the U.S.[132]

Such lending can be justified in a number of ways, but the most common method is to assume that home prices will continue to rise. On principle, this assumption is well reasoned. Land is one of the few truly scarce commodities, and property is generally an appreciating asset that serves as middle America's primary means of wealth generation. If a $100,000 home is purchased with a $98,000 mortgage, 2% equity becomes 12% equity if the value of the home rises to $112,000. If, on the other hand, the value of the home drops from $98,000 to $88,000, the little equity in the property disappears and the value of the debt drops substantially.

Decreases in home value have been occurring on a grand scale in the United States. The froth of easy credit,[133] political pressures to increase lending, and predatory lending techniques[134] led to a housing bubble. A 'bubble' is an increase in prices within an industry to a level that is not sustainable by the underlying value of the industry or assets. For example, in 2000 the market endured the "tech bubble." As the housing bubble has deflated, countless homes bought with little or no equity have lost the equity that existed and, as a result, cannot be sold for as much as is owed on them. As foreclosures began steadily mounting and housing markets began to crumble across the entire nation, the first signs of the current situation began to appear in the summer and fall of 2007.[135] Taken as an isolated problem, a nation-wide decrease in home value would have led to a relatively mild recession as consumer spending decreased to offset wealth evaporation.

Predatory Lending

A factor that exacerbated the subprime issue is predatory lending. As discussed, the financial magic of this decade allowed mortgage originators to remove most of, and sometimes all, the risk associated with providing a subprime mortgage. As a result, the fees associated with writing mortgages became a lucrative business with virtually no downside.

The laws governing lending practices are a patchwork of common law, disjointed case law, and a relatively small number of regulations. This body of law is poorly understood.[136] What is known is that this situation is perhaps one of the most glaring examples of a dangerous incentive scheme. By improperly regulating lending practices, while allowing a system to be put in place where there is no risk involved in writing mortgages, all restraints on mortgage brokers were removed. As quickly as mortgages could be securitized, they could be originated. Gone were the days of putting 20% equity into a home and providing proof of employment.

Deregulation

There has been relatively little deregulation in the US financial system during the past ten years; the single major exception to this is the Gramm-Leach-Bliley Act (GLBA). The GLBA deregulated markets by allowing commercial and investment banks to affiliate with one another, theoretically to increase competition.[137] Ironically, this act repealed much of the Glass-Stegall Act of 1933, which was enacted following the Great Depression to achieve the exact opposite result.[138] By allowing different types of financial institutions to affiliate with each other, transaction costs could be reduced, and consumers could realize significant savings.[139]

Following passage of the GLBA, the primary problem was not further deregulation but, rather, a lack of new regulations.[140] Wall Street devised and refined the financial instruments discussed in this paper. This resulted in de facto deregulation; financial firms were able to alienate and spread risk throughout the market in a manner that would have been impossible under the current regulatory scheme without new products such as CDOs and CDSs.

Division and Separation of Risk

As the housing bubble began to build, the growth of CDOs, MBSs, CDSs, and many other financial instruments began to grow exponentially. At the same time that banks were under increased pressure to make risky loans, banks were becoming larger and more stable and housing prices were rising, risk was segregated from the lending process. The creation of MBSs and CDOs allowed banks all over the country to originate a tremendous volume of high-risk loans without having to retain any of the associated risk.

Derivatives contracts such as CDSs allowed nearly every different type of risk associated with a bond (interest rate risk, liquidity risk, credit risk, market risk, etc.) to be separated and sold individually. In this way, institutions and individuals were able to build increasingly diversified and hedged portfolios that theoretically had extremely low risk.

There were three fundamental failures in these theories. First, the actual diversification was significantly less than the perceived diversification. Secondly, when the credit markets closed (although banks were originating and selling loans) banks were caught with loans slated to be sold on their balance sheets. Finally, banks often kept a portion of the equity tranche on their books under the theory that a high rate of interest would compensate for a relatively large number of defaults. In reality, these equity tranches became almost worthless.

The Ratings Game

In order for any CDO to be marketed, each tranche must be rated by the ratings agencies. Herein lies one of the largest problems. CDOs, and particularly CDO^2s, are incredibly complicated. The theory behind the CDO is that by bundling many assets into a single security (although some individual assets within the CDO might generate losses) through the magic of tranching, the AAA portion of any CDO was protected by the first loss portions. The AAA tranche of a CDO full of subprime loans or corporate junk bonds could comprise as much as 85% of the fund. To put this in perspective: AAA is the same rating held by the U.S. government.

Next, through CDO^2s and CDO^3s, the non-AAA rated portions of other CDOs could be re-collateralized into a new CDO where 85% of this new fund would be AAA rated. Through this entire process as much as 96% of all subprime loans eventually obtained a AAA rating.[141] Although there have been allegations of fraud within the rating agencies,[142] it is more likely that the rating agencies were simply unable to cope with the complexity of the instruments they were being asked to rate; and, at the same time, they were under too much pressure from various entities to approve securities for distribution.

The Skidding Halt

In Q3 2006, home values across the U.S. registered their first quarterly decline in nearly a decade.[143] Home values began to plummet, falling nearly 12% in the second half of 2007.[144] At this time the market realized some of the mortgage-backed securities that had been issued over the past five years were improperly rated.

On November 12, 2007, Fitch cut the ratings on two Security Capital CDOs.[145] The first was a $420.9 million fund. The rating on this fund was lowered from AAA to BBB.[146] The second was a $371 million fund. The rating was cut from AAA to CCC, well into junk bond territory.[147] Over the past twelve months, billions of dollars worth of asset-backed securities have been downgraded to junk bond status.

Such downgrades have had tremendous ramifications in other segments of the market. Typical buyers for AAA securities are pension funds, college endowments, and other large institutional buyers seeking superior returns over Treasuries. In many cases, these investors are restricted from investing in securities below a certain rating. Downgrades have wreaked havoc in such funds.

In order to hedge against the slim chance of this happening, many of these entities purchased insurance against the possibility of a downgrade. Insurers such as AIG or Ambac Financial (ABK) offered such insurance for relatively low premiums due to the perceived safety of AAA investments. Recent events effectively forced the U.S. government to nationalize AIG. Over the past 12 months ABK fell from nearly $30 per share to a closing of $1.34, a 95% drop, on December 2, 2008.

Moving Forward

As the country moves forward there are two distinct questions that need to be answered. First, how can we recover from the current situation? With credit markets frozen and unemployment nearing 10%, the country stands at the brink of a recession, the likes of which have not been seen since the 1930s. How the political establishment approaches this situation has the potential to define a generation. Secondly, how can the system be changed to reduce the risk of similar breakdowns in the future? This is a remarkably delicate problem, because any solution must regulate without stifling innovation.

Fixing the Present

At present three distinct problems exist that no single solution can fix. First, mountains of illiquid assets have created a level of uncertainty that has paralyzed credit markets. Secondly, the country is rapidly sinking in to an attrition driven recession;[148] fears about the market drive layoffs, which reduce consumer spending, which drives further layoffs. Finally, the rampant decrease in home values in the U.S., coupled with a near 40% decline in the stock market, has wiped out an enormous amount of wealth over the past 12 months. As an entire generation of baby boomers prepares for retirement, many are finding that more than 50% of their net worth has been erased in the last year.

An Illiquid Market

Much of the current situation can be traced to a high level of uncertainty within the market. As the trillions of dollars of CDO securities continue to fall in value, banks around the world are unable to accurately gauge their potential liabilities or the liabilities of those seeking credit. Until a "bottom" can be found, the market is likely to remain extremely volatile. Without finding this bottom to the market, fear and uncertainty will compound all of the other difficulties discussed in this section.[149]

The government's response thus far to this problem has been to approve a $700 billion 'bailout' package designed to recapitalize and backstop[150] financial institutions around the country. This solution ignores the underlying problem of uncertainty and illiquid assets. Although the health of institutions such as AIG are important to the system, until entities around the country are able to fully understand their current liabilities, credit markets will remain frozen.

The Great Recession

On December 1, 2008, it was officially reported that the U.S. sank into a recession in the Q4 2007. Over the past months, Sun Microsystems,[151] AT&T[152], and Bank of America[153] announced layoffs amounting to between 4% and 18% of their total workforce. Other stalwart firms have joined in the lay-off parade and some are going out of business. As layoffs mount and consumer spending ebbs, the threat of Depression-era deflation could resurface.[154]

A proposed answer to this problem was a new federal government stimulus package.[156] But stimulus packages merely force future generations to pay for the mistakes of the current. And it is difficult for government spending to be designed to create jobs through direct means that allows the taxpayers to receive tangible benefits from their tax dollars.[155]

Wealth Erosion

The problem of wealth erosion is a society-wide concern. All individuals take a known short-term risk by placing money in the market; with a carefully handled recovery, the market should eventually recover most of its losses. The government has already suspended mandatory withdrawals in 2009 from IRAs for seniors rather than force them to sell securities into a severely depressed market.

Fixing the Future

Perhaps the biggest question on the horizon is how to proceed in a post-2008 financial world. The global financial market has been drastically altered. The UK has partially nationalized nearly its entire banking system;[157] the Icelandic financial system has completely collapsed;[158] and the age of the investment bank seems to have ended.[159] Some new forms of regulation must be enacted in order to avoid the situation that we now face. The key, however, is not to regulate for the sake of regulating. Not all regulations are good, and there is considerable danger that policies made in response to the current market conditions could have a stifling effect for years to come.[160]

The key is not to focus on regulation *per se*, but to focus on creating a proper system of incentives. One of the greatest (and most dangerous) features of the U.S. financial system is its ability to innovate in order to maximize profits. "Greed on Wall Street was a given – almost an obligation. The problem was the system of incentives that channeled the greed."[161]

Alienation of risk

Of the many factors leading to the current crisis, the ability of banks to alienate nearly all risk from the loan origination process is perhaps the most obvious culprit. In a recent talk, Professor Tamar Frankel from Boston University opined that "[b]anks should be forced to keep some skin in the game."[162] In framing this inevitable regulation, it is important that Congress and regulators not put undue restrictions on securitization, lest they do more damage than good.

Credit Rating Agencies

"Credit rating agencies use their control of information to fool investors into believing that a pig is a cow and a rotten egg is a roasted chicken. Collusion and misrepresentation are not elements of a genuinely free market."[163] Credit agencies have experienced extreme criticism for their role in rating CDO securities. Although some of this blame is properly placed, the ratings agencies operate in a rigged system. There is a constant tension between Wall Street bankers making tens of millions of dollars and ratings agencies employees making tens of thousands of dollars. Furthermore, the agencies are compensated directly by issuers, creating a significant conflict of interest.[164] Compensation is a percentage of a given issuance determined by the size and complexity of the issuance.[165]

As so many other players in the market, the rating agencies were a product of the incentives in place.[166] With no liability for rating unratable securities and huge fees available, it was not irrational or even wrong that ratings were issued.[167] But it is the job of the government to adjust such incentives in order to protect the public.

Complex Financial Products

The final long-term problem is the government's inability to keep up with complex financial products. There is no simple solution to this quandary; it is almost impossible to foresee exactly what new financial products will exist ten years hence. In 1991 the first CDO was born; no government regulator could possibly have seen the havoc it would help to sow in 2008.

Note that the average salary at the Securities and Exchange Commission (SEC) was $64,000 in 2008.[168] This stands in stark contrast to companies such as Goldman Sachs where the average salary was $622,000 in 2006.[169] With such discrepancies, there is going to be a natural difference in the quality of recruits at these two entities. The federal government regulating agencies should be funded in such a way (and create incentives) that allow them to recruit on par with top Wall Street Banks. Strategies to accomplish this include competitive starting salaries (in the $120,000 range), aggressive bonus structures, and intangible benefits, such as time off for lecturing at universities or writing.

Conclusions

The market currently rests on a precipice awaiting dramatic change. Events over the past ten years have necessitated such change by plunging the economy into a state of disarray not seen since the Great Depression. Moving forward, the key is to apply measures designed for long-term stability, not born of short-term reaction.

Appendix A

Arbitrage CDO – A CDO designed to exploit the artificially large spread between investment grade corporate debt and "junk" bonds. Due to the fact that many institutional buyers are precluded from purchasing junk bonds, arbitrage CDO's can capitalize by turning junk bonds into AAA rated securities through the CDO tranching process.

Balance Sheet CDO – A CDO formed for the express purpose of moving potential liabilities and credit risk off an entity's balance sheet.

Cash CDO – A traditional CDO of asset-backed securities

Collateralized Bond Obligation (CBO) – A CDO backed primarily by corporate bonds.

Collateralized Debt Obligation (CDO) – A bundle of assets that are securitized and tranched into separate securities, each bearing a different credit rating.

Collateralized Debt Obligation Squared (CDO^2) – A CDO comprised primarily of other CDO tranches.

Collateralized Mortgage Obligation (CMO) – A CDO backed primarily by mortgage obligations.

Credit Default Swap (CDS) – A derivative contract whereby one party pays a series of premiums to another in exchange for a payoff if a certain credit event comes to pass. For example, party A might pay premiums of $40 per month to purchase protection against a default on GM debt. If GM defaults, party B will owe party A a one time payment of $1,000.

Equity Tranche – The lowest rated tranche in a CDO, generally between 3% and 5% of the total offering and often kept on a bank's balance sheet.

Originator- Throughout this paper, the term originator is used to refer to any entity that 'originates' loans, i.e. issues debt. A father can be an originator by loaning his son $10,000 for school as easily as a bank can be an originator by holding 200 mortgages. The difference between the bank and the father is that the bank may sell the loan, creating a distinction between it being the originator and another entity that actually holds the debt.

Single Tranche CDO – In a single tranche CDO, the issuer designs the entire CDO for a single buyer (generally institutional) and retains the remainder of the CDO. This allows for a CDO to be built very quickly to a buyers specifications.

Synthetic CDO – A synthetic CDO is a CDO with no underlying assets but instead bundles credit derivatives to simulate the risk of a cash CDO. For example, suppose an issuer wanted to create a $100 million CDO with three tranches, yielding 7%, 11%, and 15% respectively. Further, the issuer is not interested in purchasing mortgage backed securities or other hard assets. Instead, the issuer could simulate the appropriate degree of risk by purchasing and selling Credit Default Swaps and other credit derivatives. By selling CDSs, the issuer is effectively generating a stream of insurance premiums in place of mortgage payments. If the mortgagor defaults on their payments, this triggers liability on the part of the issuer. Thus, a properly crafted portfolio of CDSs can simulate the same level of income and risk as a CDO backed by mortgages.

Tranche- A tranche is a 'slice' of a security. To use a very simple example, assume that new corporation X wants to issue stock. Rather than issue all the stock at $8 per share, it might issue 3 'tranches' of stock. The first tranche will be entitled to a 7% dividend, no equity appreciation, and a security interest in the corporation's holdings. The second tranche will be entitled to a 9% dividend, no equity appreciation, and have only an unsecured interest in the company's holdings. The final tranche is entitled to a 4% dividend, no security interest in the company's assets, and full equity appreciation on the company's value. In this case, the three 'tranches' are known much more simply as debt, preferred stock, and common stock. Tranches are just a fancy term to describe different levels or slices of securities with different rights pertaining to the same underlying assets.

References

1. www.nacubo.com, College and University Endowments Realize 8.6% Average 10-Year Return, Jan 24, 2008, http://www.nacubo.org/documents/research/News%20release%20&%20fact%20sheet_2007_NES.pdf.

2. Associated Press, Subprime crisis shouldn't hurt many funds, CHICAGO TRIBUNE, Mar. 14, 2007, at 7

3. Henceforth the Dow Jones Industrial Average will be used as a proxy for the market. Although an argument can be made that 30 stocks serve as a poor proxy for the greater market, other indices have moved very closely with the Dow, making it a good enough gauge for the current crisis.

4. On December 4, 2008, the market stood at 8500, 5500 points off its high.

5. As of November 2, 2008.

6. For a variety of "jargon" terms throughout this paper, an appendix has been provided. When not adequately explained within the body of the paper, look to the appendix for further clarification.

7. Throughout the paper the term 'Wall Street" will be used in the colloquial sense that it has evolved into. That is as a stand in for investment banks, corporate executives, underwriters, and generally the movers and shakers in the financial world.

8. Also known as special investment vehicle.

9. CDOs have moved to the third dimension and beyond. These will be explained at a later point in this section.

10. Incentives is really just a non threatening way of saying regulations. By putting together the proper regulatory framework the various actors in a free market can have incentives to continue innovating without creating a perfect storm where the system collapses.

11. The "Crisis" will henceforth refer to the current economic situation rather than the plethora of stand-in terms that are currently being used such as the subprime meltdown, subprime crisis, credit crisis, etc.

12. Tax Reform Act of 1986, 26 USC § 1 et seq.

13. Id.

14. Id.

15. Id.

16. 12 U.S.C. § 1723(b) (2006) (Fannie Mae); id. § 1452(a)(2)(A) (Freddie Mac).

17. Id. at § 4541; Id. at 4513.

18. Id. at § 1719(b) (Fannie Mae); Id. at §1455(j) (Freddie Mac).

19. Id. at § 1433.

20. Id. at § 1455(g).

21. Id. at §§ 1455(c), 1719(c).

22. See id. §§ 1452(d), 1723a(g). See also Richard Scott Carnell, Handling the Failure of a Government-Sponsored Enterprise, 80 WASH. L. REV. 565, 582 (2005).

23. See U.S. General Accounting Office, Housing Enterprises: Potential Impact of Several Government Sponsorship, 17 (1996); For a more complete view of Fannie and Freddie and their history, see Julia Patterson Forrester, Fannie Mae/Freddie Mac Uniform Mortgage Instruments: The Forgotten Benefits to Homeowners, 72 Mo. L. Rev. 1077 (2007).

24. See Franklin, G., "The Secondary Market" Syndicated Lending: A Handbook for Borrowers in Emerging Markets. Ed. Saurabh Murkherjea (London: Euromoney, 1999) 132.

25. 12 U.S.C.A. § 2901 (1977).

26. FederalReserve.gov, Community Reinvestment Act, http://www.federalreserve.gov/dcca/cra/ (last visited Nov. 4, 2008). For a fuller discussion of the CRA's past and future, see Michael Malloy, Towards a National Community: The CRA and the Contemporary Market, W. New Eng. L. Rev. 25 (2006).

27. Id.

28. Steven Holmes, Fannie Mae Eases Credit To Aid Mortgage Lending, N.Y. TIMES, Sept. 30, 1999.

29. Id.

30. Gramm- Leach-Bliley Act, Pub. L. No. 106-102, Nov. 12, 1999 Stat. 1338 (1999). The act is discussed in detail infra, Section XX.

31. Pub. L. No. 73-66, 48 Stat. 162 (1933) (also known as the Banking Act of 1933).

32. ftc.gov, In Brief: The Financial Privacy Requirements of the Gramm-Leach-Bliley Act, http://www.ftc.gov/bcp/edu/pubs/business/idtheft/bus53.shtm, (last visited Nov. 15, 2008).

33. For a more complete discussion of the Glass Seagall Act and the Gram-Leach-Bliley Act, See Mathew Restrepo, The Convergence of Commercial and Investment Banking Under the Gram-Leach-Bliley Act: Revisiting Old Risks and Facing New Problems, 11 L. Bus. Rev. Am. 269, (2005).

34. Alex Berenson, Fannie Mae's Loss Risk is Larger, Computer Models Showing, N.Y. TIMES, Aug. 7, 2003.

35. 94 Fed. Res. Bull, Statistical Supplement, 1.54 (Oct. 2008).

36. Id.

37. Frankel, 5.

38. E.g., Exclusion from the Definition of Investment Company for Structured Financing, IC-19105 (Nov. 19, 1992) (adopting Rule 3a-7 "to exclude issuers that pool incoming-producing assets and issue securities backed by those assets).

39. Id.

40. Frankel 46

41. See Id.; See generally Wimarth, The Transformation of the U.S. Financial Services Industry, 1975-2000: Competition, Consolidation, and Increased Risks, 2002 U. Ill. L. Rev. 215, 378-388 (2002).

42. E.g., Kurtz, Loan Participations after Penn Square, Int'l Fin. Ll Rev. at 24 (1982).

43. Gramm- Leach-Bliley Act, Pub. L. No. 106-102, Nov. 12, 1999 Stat. 1338 (1999); There are a variety of other advantages to LPs, including allowing banks to effectively lend in states that consider lending "doing business" and to capitalizing on less restrictive usury laws.

44. See Frankel at 49.

45. Id. The process of securitization is examined in more detail infra at section III D.

46. Education Amendments of 1972, Pub. L. No. 92-318, §439(b), 86 Stat. 234, 265, codified as amended at 20 U.S.C. former § 1087-2(b).

47. See Frankel at 51.

48. See 76 Fed. Res. Bull. At A38 Table 1.54 line 44 (Mar. 1990).

49. This includes only securities issued by Ginnie Mae, Fannie Mae, and Freddie Mac. See Securities Industry and Financial Markets Association, Agency Mortgage-Backed Securities Outstanding, http://www.sifma.org/research/pdf/AgencyMortgageOutstanding.pdf (last visited Nov. 16, 2008). Non-Agency issued "securitizes" could add an additional $3 trillion to this total, placing the aggregate total of MBS at roughly $9 trillion.

50. Mortgage Backed Securities, RBS Wealth Management, http://www03.50below.com/33/330/File/MBSs.pdf (last visited Nov 15, 2008).

51. See Securities Industry and Financial Markets Association, Asset-Backed Securities Outstanding, http://www.sifma .org/research/pdf/ABS_Outstanding.pdf (last visited Nov. 16, 2008). The asset classes included in this total are automobile loans, credit card receivables, equipment leases, home equity loans, manufactured housing, and student loans. All other classes have been aggregated separately as an 'other' category in the cited study.

52. E.g., Hill, Securitization: A Low-Cost Sweetener for Lemons, 74 Wash. U.L.Q. 1061, 1076 (1996) (the auto loan securitization market exceeded $35 billion by January 1, 1995) . Total outstanding securities as of Q2 2008 for auto loans was $199 billion.

53. See Lupica, Asset Securitization: The Unsecured Creditor's Perspective, 76 Tex. L. Rev. 595, 603 (1998) (a pool of $500 million in pharmacy receivables was issued).

54. See Chen, Don't Sell Out, Sell Bonds: The Pullman Group's Securitization of the Music Industry An Interview with David Pullman, 2 Vand J. Ent. L. & Prac. 161, 162 (2000).

55. See Pointexter, Rogovoy & Wachter, Selling Municpal Property Tax Receivables: Economics, Privitization, and Public Policy in an Era of Urban Distress, 30 Conn. L. Rev. 157 (1997).

56. See Pavel, Securitization, Econ. Persp. At 16-22 (July-Aug 1986).

57. See Kravitt & Raymond, Overcoming the Legal Barriers to Auto Lease Securitization (May, 1995).

58. See Lupica, Asset Securitization supra n. 47, at 603.

59. Arnold, Strategies in Securitizating Non-Mortgage Assets (First Boston Corp.), Securitizing Financial Assets, Executive Enters. Inc. Seminar, New York (Oct. 5-6, 1987).

60. Saladino, Securitization of Municipal Obligations in the Secondary Market: The California Legislative Response, 28 Urb. Law. 1 (1996).

61. Kantrow, Card Issuers Find Market for Bad Debt, Am. Banker at 1, Col. 3 (Oct. 17, 1991).

62. Financial Co. Plans Beauty Backed Bond Offering, Corp. Fin. Wk. at 2 (Nov 6, 1995).

63. Alexander, Tax Liens, Tax Sales, and Due Process, 75 Ind. L. J. 747, 761 (2000).

64. In 1997, a $55 million bond was issued, backed by the future royalty stream from David Bowie's recording made prior to 1990. Karen Richardson, Bankers Hope for a Reprise of 'Bowie Bonds,' Wall St. J., http://online.wsj.com/public/article/SB112476043457720240Tvpthd07S8mCqCxLFNKIPnWWY9g_20060823.html?mod=tff_main_tff_top, (last visited Nov. 15, 2008).

65. See Harrell, Rice & Shearer, Securitiziation of Oil, Gas, and Other Natural Resource Assets: Emerging Financial Techniques, 52 Bus. Law. 885 (1997).

66. See Plesset & Ambler, The Financing of Mutual Fund "B Share" Agreements, 52 Bus. Law. 1385 (1997).

67. See Comment, "Bankers Up!" Professional Sports Facility Financing and Other Opportunities for Bank Involvement in Lucrative Professional Sports, 3 N.C. Banking Inst. 202, 226 (1999).

68. See Mann, Secured Credit and Software Financing, 85 Cornell L. Rev. 134, 172 (1999).

69. Lebron, First Things First: A comment on Securitizating Third World Debt, 1989 Colum. Bus. L. Rev. 173 (1989).

70. Risk is reduced through guarantees against third party collateral or other means.

71. Frankel at 55-56; Brendt C. Butler, Asset-Backed Securitization, Special Purpse Vehicles and Other Securitization Issues, SJ082 ALI-ABA 55 (2004).

72. SPV's come in a variety of forms. They may be wholly owned subsidiaries of the loan originator, subsidiaries of third parties, or formed by government sponsored entitles such as Fannie Mae and Freddie Mac.

73. See Appendix for Clarification.

74. This represents a slightly oversimplified example. SPVs can take on other liabilities that can present a variety of risks to investors. For the purposes of this paper we will not focus on the many complexities of SPVs. For further information on the topic see Frankel at 59-66.

75. In Tamar Frankel's treatise on securitization that has been oft quoted in this paper, she write's a tone point "Securitization produces huge securities Markets, and Markets pose the risks of extreme volatility. However, as between market liquidity (that securitization offers) and illiquidity (provided by the traditional structure of the banking system), liquidity may be preferable." Frankel at 44. These words, written in 2005, seem to almost foretell the storm that the markets are currently enduring and may cause some to ponder the very question of whether it is in fact preferable.

76. For an in depth look at the process and legal framework behind Securitization see Frankel.

77. Merrill & Smith, The Property/Contract Interface, 101 Colum. L. Rev., 773, 845- 46 (2001) ("Mutual funds and to a lesser degree securitization" are regulated through regulatory schemes that "tend to take the form of mandatory information disclosure rather than nonwaivable fiduciary duties.")

78. Finance Brief, Economist, June 14, 1986, at 70 -71.

79. In general, the higher the information costs behind a given security the more difficult it would be to rate. Thus, rating a single debt issuance of GE is much easier than rating a bundled security of 200 different mortgages around the country.

80. See Sandy Hock, Imperial's Sour Real Estate Loans Dot the Country, San Diego Bus. J. (1990).

81. Copulas are mathematical equations that help predict the likelihood of events occurring that depend on each other. Li found that the best copulas for bond pools was one named after Carl Friedrich Gauss, a 19th century German statistician. Mark Whitehouse, How a Formula Ignited Market That Burned Some Big Investors, Wall St. J., Sept. 12, 2005 http://online.wsj.com/article/SB112649094075137685.html (last visited Nov. 17, 2008).

82. Id.

83. Financial Markets Association, Agency Mortgage-Backed Securities Outstanding, http://www.sifma.org/rese arch/pdf/SIFMA_CDOIssuanceData2008q3.pdf (last visited Nov. 16, 2008). The number will probably hover at $2.5 trillion for the foreseeable future, as the entire CDO market has frozen due to current market conditions.

84. These are comprised completely of medium and large business loan obligations. CLOs have made it possible for small and medium business to reduce their borrowing costs by allowing purchasers of the securities to diversify their bond holdings across a broad range of companies through owning a single CLO.

85. These are made up entirely of corporate bonds.

86. Predictably these are CDOs comprised only of mortgage backed assets. In this case, the differences between a MBS and a CDO are slightly more subtle, with the MBS being a subset of the CMO.

87. Henceforth in this note, the terms CDO, CMO, CLO, etc will all be used interchangeably. The only difference is the makeup of the assets backing the fund based on the examples being given.

88. Gary Barnett, Understanding CDOs, 1653 PLI/Corp 437 (Feb. 2008).

89. For the purposes of this note, all ratings will be according to the Standard and Poor's rating system.

90. This tranche is often referred to as the 'first loss piece.'

91. Id. at 411.

92. Id. at 441. In the past, the originator was forced to keep at least a portion of the equity tranche on their books. As the market became flooded with investors seeking a greater return on capital, originators have been able to sell greater and greater portions of this highest risk tranche, enabling them to shed ever-increasing levels of risk when selling CDO securities. Find Source! See Omni Doc.

93. See Appendix A.

94. These numbers have been exaggerated for the purpose of this example. In reality the spreads on a non subprime CMO would be much tighter.

95. The most risk averse player's chances of not receiving his $1.06, assuming ten standard dice are rolled is equal to (1/6)^10 = .0000000282.

96. Mathew Attwood, Creating CDO Tranches, CREDIT, Aug. 2004, http://www.creditmag.com/public/showPage.html?page=168502. (last visited Nov. 17, 2008).

97. Id. A discussion of fixed, floating, and inflation-linked tranches is outside the scope of this note. For an in depth discussion of such complexities, see FIND ARTICLE.

98. See Barnett at 442.

99. In reality this last bit is far beyond the resources of the credit agencies. In recent years evaluating the credit worthiness of the mortgagor has even been ignored by the originator of the loans. This is the subject of an entirely different paper.

100. Id.

101. A discussion of Credit Default Swaps can be found infra Section V. Also see Appendix A infra.

102. Frank Partnoy, David A. Skeel, The Promise and Perils of Credit Derivatives, 75 U. Cin. L. Rev. 1019, 1022 (2007). Also see Appendix A for another example.

103. See Partnoy at note 22.

104. FIND SUPPORT

105. Banks, pension funds, insurance companies, mutual funds, etc. These restrictions are generated both internal and by regulations. See FIND CITATION.

106. Thus, these securities are deemed to have the equivalent level of safety as the U.S. Government or General Electric.

107. Sifma.com, Global CDO Market Issuance Data, 2007, http://archives1.sifma.org/assets/files/SIFMA_CDOIssuanceData2007q1.pdf

108. See Appendix A

109. Delta hedging uses credit derivatives to hedge against price movements of an asset. For instance, a classic delta hedge is purchasing a put option on a stock that is being held long.

110. Mathew Attwood, Creating CDO Tranches, CREDIT, Aug, 2004, http://www.creditmag.com/public/showPage.html?page=168502.

111. Id.

112. See, e.g., Antulio N. Bomfim, Understanding Credit Derivatives and Related Instruments 3- 5(2005).

113. This amounts to over 16 times America's GDP. Robert F. Schwartz, Risk Distribution in the Capital Markets: Credit Default Swaps, Insurance and a Theory of Demarcation, 12 Fordham J. of Corp. & Fin. L 167 (2007);

114. On Top of the World: In Its Taste for Risk, the World's Leading Investment Bank Epit - omises the Modern Financial System, The Economist, Apr. 29, 2006, at 11.

115. See, e.g., Hamish Risk, Credit Derivatives Market Expands to $17.3 Trillion (2006) available at http://www.bloomberg.com/apps/news?pid=10000103&sid=a9mg9712QnRU&refer=us.

116. See Schwartz at 175. Determining a triggering event can become substantially more difficult when the CDS is purchased against sovereign wealth fund, CDO, or SPV. Credit

events in reference to these entities are much more difficult to judge, and a "reference entity" must generally be chosen. Id.

117. See Partnoy at 1022.

118. Wsj.com, John Paulson's Hedge Funds Return 19% in a Down Market, Oct. 1 2008, http://blogs.wsj.com/deals/2008/10/01/john-paulson-the-hedge-fund-manager-actually-making-money-in-the-market/.

119. The underlying CDOs are generally synthetic CDOs created in part for the purpose of feeding the master CDO.

120. Michiko Whetlen, Mark Adelson, CDO's Squared Demystified, Normura Fixed Income Research, (Last Visited Nov. 16, 2008).

121. Kai Gilkes, Mike Drexler, Drill-Down Approach for Syunthetic CDO Squared Transactions, Standard & Poors, Link (Dec. 10, 2003) (Reprinted at LINK).

122. Id.

123. .Link by Link, The Economist, Oct. 16, 2008, http://www.economist.com/display story.cfm?story_id=12415730.

124. Id.

125. Michael Lewis, The End of Wall Street's Boom, Portfolio.com, Dec. 2008, http://www.portfolio.com/news-markets/ national-news/portfolio/2009/11/11/The-End-of---Wall-Streets-Boom.

126. Joe Conason, Bring Wall Street Crooks to Justice, N.Y. OBSERVER, Sept 24, 2008, http://www.observer.com/2008/politics/bring-wall-street-crooks-justice ("From the bottom-of-the-barrel bucket-shop mortgage salespeople, who sought inspiration and technique from the movie Boiler Room, to the geniuses who packaged those bad and often fraudulent loans into bad paper for sale to major banks, investment houses and insurance companies, literally thousands of crooks are out there.")

127. 127.Nytimes.com, The Republican Party, Having Brought you the Meltdown, Now Blames Obama, N.Y. TIMES, Sept. 30, 2008, http://theboard.blogs.nytimes.com/2008/09/30/the-republican-party-having-brought-you-the-meltdown-now-blamesobama/?scp=2&sq=republican%20subprime%20fault&st=cse.

128. Merely turn on Rush Limbaugh or most other Conservative talk radio shows to find a plethora of blame being heaped on the Democrats.

129. Charles W. Calomiris, Most Pundits are Wrong About the Bubble, WALL ST. J., Oct. 18, 2008, http://online.wsj.com/article/SB122428270641246049.html.

130. FICO is a registered trademark of the Fair Isaac Corporation.

131. FICO scores are generated from a mathematical formula incorporating all available credit information about a consumer including mortgage debt, credit card history, student debt, etc. Scores range from 300 to 850. People with low FICO scores are the equivalent of corporations that can only issue junk bonds due to insufficient cash flows and too much levereage.

132. In recent years, a variety of hybrid mortgage structures has been created that blend the features of fixed and ARM mortgages. For the purposes of this paper, these hybrid mortgages will fall into the category of ARMs.

133. Mbaa.org, Delinquencies and Foreclosures Increase in Latest MBA National Delinquency Survey, http://www.mbaa.org/NewsandMdia/PressCenter/58758.htm (last visited Dec. 2, 2008).

134. Attributed at least in part to the Federal Reserve's reluctance to raise interest rates following the 2000-2002 recession.

135. An entire paper could be written on predatory lending techniques and the patchwork of regulations, common law, and self regulation that failed to properly govern lending practices

136. See n. 1, *supra.*

137. The intricacies of the law behind predatory lending is unfortunately outside the scope of this paper.

138. 145 Cong. Rec. H11255 (daily ed. Nov. 2, 1999) (statement of Rep. Leach).

139. See note 29, *supra.*

140. Christopher Wolf, 2005 Overview of the Gramm-Leach-Bliley Act, 828 PLI/Pat 761, 765 (May-June 2005);For a more thorough discussion of the GLBA, *see* Kathleen A. Hardee, *The Gramm-LeachOBliley Act: Five Years After Implementation, Does the Emperor Wear Clothes?,* 39 Creighton L. Rev. 915 (2006).

141. Or proper incentive structures.

142. Tamar Frankel, Professor, Boston University School of Law, Talk at Barristers Hall, Boston University (Oct. 14, 2008).

143. Dealbreaker.com, Rethinking The Ratings Agency Scandal, Part IV: Homogenous Ratkings Labels For Heterogeneous Credits, http://dealbreaker.com/2008/02/rethinking-the-ratings-agency-2.php (last visited Dec. 2, 2008).

144. S&P/Case-Shiller U.S. National Home Price Values, Q3 2008 (published Nov. 25, 2008). The last quarterly decline was Q4, 1996. *Id.*

145. As of December 2, 2008, home values across the U.S. had fallen 21% with no definite sign of a bttom to the market in sight. *Id.*

146. Alistair Barr, Security Capital Hit by CDO Downgrades, Market Watch, http://www.marketwatch.com/news/story/security-capital-hit-cddo...rades/story.aspx?guid=%7B7D035313-B075-46BE-A5F7-6A173EC8EB8A%7D, last visited December 2, 2008.

147. *Id.*

148. *Id.*

149. Attrition driven in the sense that as consumers spend less due to a perceived lack of wealth (as their homes decrease in value), corporations are forced to lay off workers, leading to less spending and more layoffs.

150. As a more intuitive example, consider the standard horror film. Very often it is far more effective to leave the actual form of the villain or monster unknown in order to allow the audience's own fears to conjure an image that the movie studio would be unable to match. The exact same phenomenon is occurring in the market now.

151. Effectively guarantee the liabilities of a given institution.

152. Don Clark, Sun Micro Slashes Jobs, Wall Stl J., Nov. 15, 2008, http://online.wsj.com/article/SB122666922420228145.html (Sun Microsystems is cutting 5,000 to 6,000 employees, or 15% to 18% of its total work force).

153. Peter A. McKay, Dow Tumbles $215.45 Points on Worries of Job Losses, WALL ST. J., DEC. 5, 2008, http://online.wsj.com/ article/SB122845338007682489.html. (AT&T to cut 12,000 jobs).

154. Dan Fitzpatrick and Susanne Craig, BofA to Cut 35,000 Jobs as it Absorbs Merrill Lynch, Wall St. J., Dec. 12, 2008, http://online.wsj.com/article/ SB122901448971498505.html#articleTabs%3Darticle.

155. Phill Izzo, FedEx Cuts Wages, Will Other Companies Follow?, Wall St. J. Dec. 18, 2008, http://blogs.wsj.com/economics/2008/12/18/fedex-cuts-wages-will-other-companies-follow/.

156. Theoretically, stimulus packages create jobs by allowing consumers to spend more money which in turn creates jobs.

157. Carried interest is a cut of all profits over a predetermined hurdle rate such as 7%. Given the size of the fund, it should be structured into a great number of smaller funds targeted at certain industry segments such as clean energy, telecom, etc. Venture capitalists could be enticed to work outside their current fee structure in a number of ways but most importantly is their ability to invest along side the fund.

158. Associated Press, U.K. Government to Partially Nationalize Banks, msnbc.com, Oct. 8, 2008, http://www.msnbc.msn.com/id/27078582/.

159. See Hannes H. Gissurarson, Iceland Abandoned, wsj.com, Nov. 17, 2008, http://online.wsj.com/article/SB122695569056034695.html.

160. Three of the five major investment banks have disappeared (Bear Stearns, Lehman Brothers and Merrill Lynch), while the other two have converted into bank holding companies, Goldman Sachs and J.P. Morgan.

161. For an example of a debatable over burdensome regulatory scheme passed in a fervor of public sentiment, see the Sarbanes-Oxley Act of 2002, Public L. No. 107-204, Sec. 806, codified at 18 U.S.C. § 1514A.

162. Lewis, n. 124, *supra*.

163. Tamar Frankel, Professor, Boston University School of Law, Talk at Barristers Hall, Boston University (Oct. 14, 2008).

164. U.S. Congressman Gary Ackerman.

165. Approximately 90% of rating agency revenue comes from issuers who pay for ratings. Frank Partnoy, How and Why Credit Rating Agencies Are Not Like Other Gatekeepers, San Diego Legal Studies Paper No. 07-46 (2006), http://www.tcf.or.jp/data/20050928_Frank_Partnoy.pdf. Citing

166. Id.

167. Assuming the agencies gave a fair rating to the best of their ability. Due to the lack of competition there is no pressure on the agencies to give particularly good ratings, so it is assumed that there was no outright fraud in overrating securities.

168. Simplyhired.com, Average SEC Salaries, last visited Dec. 23, 2008, http://www.simplyhired.com/a/salary/search/q-SEC.

169. Robert Gavin, Good Deal: Average Goldman Sachs Employee Makes $622,000, Bosotn.com, Dec. 12, 2006, http://www.boston.com/business/articles/2006/12/12/good_deal_average_goldman_sachs_employee_makes_622000/.

Biographical Information

Mark Kasdorf received the B.A. in Mathematics degree from Hamilton College in Central New York with a year studying mathematics at Oxford University, England. He is completing the final year for a Juris Doctorate in May 2009 at Boston University School of Law. He is Founder and CEO of Burning Hollow Technologies, a cutting edge startup in the home automation industry.

AN EFFICIENT PID CONTROL TEACHING MODULE WITH LABVIEW SIMULATION

Jiancha Yao, Loren Limberis, Rick Williams, and Ed Howard
Department of Engineering,
East Carolina University
Greenville, NC 27858

Abstract

This paper presents the development and applications of an innovative teaching module for Proportional-Integral-Derivative (PID) control theory. The teaching module consists of a *LabVIEW simulator* and a *PowerPoint presentation*. The module uses a step-by-step approach to teach control concepts, control system performance measures, and PID control tuning. The LabVIEW simulator provides direct visual feedback using the level of a liquid storage tank as the control object; the PowerPoint presentation compares simulation results and explains P, I, and D control components in an intuitive manner. The module allows students to learn by doing, starting with implementing a simple manual control system in LabVIEW, and progressively leads them to P, PI, and PID control schemes. We have used the module to introduce engineering to high school students and teach general engineering students PID controller in a junior-level *Instrumentation and Controls* course. The experiences have demonstrated that this strategic integrated teaching approach can serve as an efficient teaching platform that can be conveniently modified for a range of teaching needs.

Introduction

Despite the emerging of an increasing number of sophisticated control algorithms in the academic research field, PID control dominates 95% applications in industrial process control even in today's highly integrated control systems [1]. Long before it was rigorously treated in mathematics by Minorsky in 1922 [2], concepts of PID control had been used, implicitly or explicitly, in early control devices. Introducing PID control to engineering students not only teaches them an important control method that is widely used in the real-world, it also brings up an interesting historical review of development and evolution of control theories. Therefore, PID control is a topic usually covered in engineering control courses.

Delivery of PID control with the lecture plus laboratory pedagogical approach [3] has been proven to be effective and has been endorsed by many traditional, disciplined engineering curricula. However, a dilemma surfaces when it comes to teaching this topic in general engineering programs, where courses covering controls topics are fundamental parts of the curricula. According to recent research, all System Engineering (which is often part of general engineering) curricula include at least one controls course [4]. As many disciplined engineering programs see conflicts between the expansion of engineering curricula and practical constraints (e.g., limited credit hours, available instructors, and facility resources), general engineering programs experience much greater challenges in this matter, because they usually have to carry much more compact curricula [5] to cover a broader range of engineering topics.

Virtual laboratories, or simulations based on mathematical models implemented on computers, can be adopted as an alternative to achieve the same learning outcomes as their standard physical counterparts [6-9]. Studies have shown that the new delivery mode provides students with equivalent experiences and no significant differences have been noticed when comparing student learning using physical laboratories versus virtual laboratories [10]. Some research even reported that students who conducted virtual experiments showed deeper levels of cognition in data analysis [11]. It can be concluded from these references that virtual laboratories can successfully support student learning [12].

A number of virtual laboratories for teaching PID-related topics have been developed, most of which were implemented in MATLAB® [13-16]. MATLAB and its Simulink® toolbox are excellent tools for simulating and presenting results for control topics like system modeling, time and frequency responses, performances of open- and closed-loop control systems, etc. [17-19]. However, it usually requires significant programming time to design a meaningful graphical user interface that can provide students insights into dynamic systems.

This paper presents an innovative module to teach feedback and PID control concepts. The module strategically integrates three approaches to enhance the teaching-learning effectiveness: 1) visualization of control performance with a LabVIEW simulator; 2) intuitive presentation of P, I, and D control components; and 3) students progressive learning by doing. The remainder of this paper is structured as follows: Section II describes a) the development of the first two major components of the module, b) how the two components were integrated in lectures, and c) how students were walked step-by-step through the design of a complete PID control system. Section III reports results from two applications of this teaching module. Section IV summarizes the benefits of the proposed teaching module and discusses pitfalls based on these experiences.

Methods

The two instructional components in the proposed teaching module are a LabVIEW simulator and a PowerPoint presentation. The former primarily include a user interface and three functional units. The latter covers necessary control concepts. The two components, when used in lectures, are integrated to deliver the material.

The Tank-Level Simulator with LabVIEW

The first component of the module is a LabVIEW simulator. The system simulated is a liquid storage tank. The level of the liquid storage was utilized as the control object in the simulator. This was chosen for a number of reasons: a) tank level control systems are frequently seen in bioprocessing and chemical-related industries; engineers in these industries are often required to work on such systems; b) compared to other control objects (e.g., motor speed), fluid levels have reasonably long time constants that allow the students to visually observe the level changes without assistance of any electronic equipment; and c) tank level is intuitive and easier to be visualized than other physical parameters (e.g., velocity or force) and this direct visual effect facilitates the students' natural understanding of transient responses of dynamic systems.

LabVIEW, a graphical software programming environment for data acquisition [20], is utilized to implement the simulator. LabVIEW is widely used for process monitoring and control in industry; it is also popularly used as virtual instruments (VIs) in research/academic environments. LabVIEW provides a wealth of features, including graphical components for user interface design, built-in functions for signal processing, communication/connectivity, data analysis, trend display, data storage, etc. Thanks to its drag-and-drop programming method, one can conveniently implement sophisticated applications in a LabVIEW development environment without having the knowledge of advanced programming codes. The tank level simulation primarily takes advantage of LabVIEW's rich graphical components to construct a tank system with control devices and control performance indicators.

The development of the LabVIEW simulator consisted of four primary tasks (refer to Figures 1 and 2): a) design a straightforward graphical user interface, b) develop a mathematical model of the tank system,

c) implement a digital PID controller, and d) develop the LabVIEW unit for measuring the control performance. Each of these four tasks is explained with greater details in the following subsections.

a. The User Graphical Interface

The graphical user interface (LabVIEW front panel) of the simulator shown in Figure 1 consists of three elements. These include:

1) *A tank system* (on the upper half of the interface): This system includes a tank with a level gauge and a required input/output piping system (an input pump, an input valve, and an output valve). To mimic the real operation of a fluid system, the pump and valves are set to work in an ON/OFF mode which will allow or stop flow of the fluid in the piping system.

2) *A control panel* (on the right-hand-side): This panel allows the user to adjust system settings and control coefficients. Adjustable parameters include P, I, D coefficients, tank-level set point, and tolerable error band (usually 5% or 2%).

3) *A control performance display unit* (on the bottom left of the interface): This unit shows the continuous change of the tank level compared with the level set point in the same plot. It can also numerically report the control performance measures of the system: *rising time* (t_r, in minutes), *settling time* (t_s, in minutes), *percentage overshoot* (P.O, %), and *stead-steady error* (SSE, %). The level change and performance measures are all updated in a real-time manner.

b. The Mathematical Model of a Tank System

In the simulator, a cylindrical tank with a diameter of 3 feet and a height of 10 feet was used as the control object. At any time $\mathbf{t}$, the fluid level H(t) in the tank is given by:

$$H = \int_{t_0}^{t} \frac{Q_i - Q_o}{A} dt \qquad (1)$$

where Q_i is the input flow rate; Q_o is the output flow rate; t_0 is starting time; and A is the cross sectional area of the tank (28.3 ft^2).

In the simulator, the tank level H is obtained through a numerical integration using Euler's method over time, where the step-length Δt depends on the simulator's sampling rate.

$$H(n) = H(n-1) + \frac{Q_i - Q_o}{A} \Delta t \qquad (2)$$

where: $H(n)$ is the tank level of the current sample cycle; and $H(n-1)$ is the level of the previous sample cycle.

In a controlled tank system, the designed controller determines the input flow rate $Q_i(n)$. The output flow rate $Q_o(n)$, derived by applying the steady state fluid energy equation to the system, is:

$$Q_o(n) = A_d \sqrt{\frac{2gH(n)}{1+K}} \qquad (3)$$

where: *H(n)* is the tank level; K is the loss coefficient for the exiting pipe system; A_d is the cross sectional area of the drain tap of the tank; and g is the gravitational acceleration constant (32.2 ft/s^2).

To simplify the development work, the tank system was modeled with a few approximations without sacrificing the conveying of concepts. We assumed that input flow has an unlimited supply; i.e., the desired input flow rate—determined by the output of the PID controller—can reach any value obtained from the control algorithm. It is also assumed that an overflow mechanism exists so that when the mathematically calculated tank level exceeds the maximum tank capacity, the tank level is forced to equal the maximum tank height (10 feet in our model). Also, we did not fully

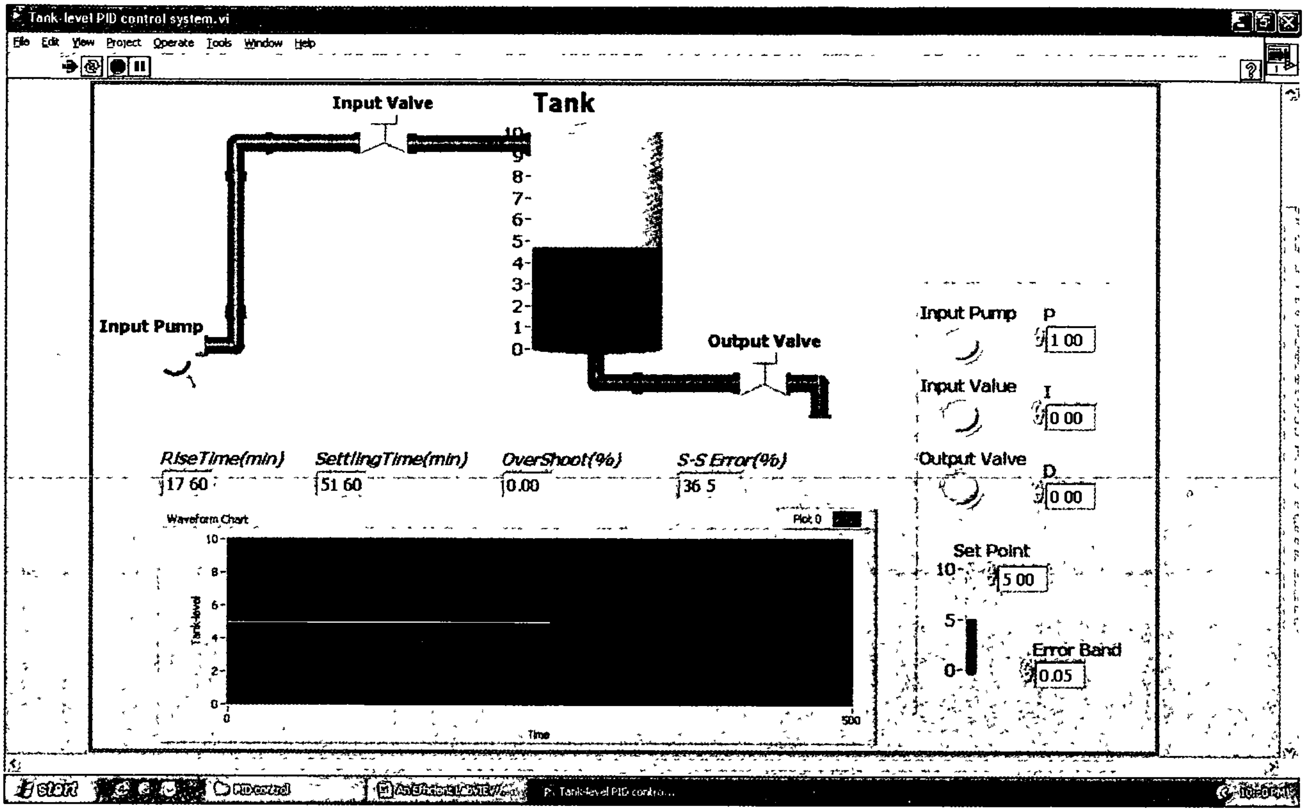

Figure 1. The LabVIEW User Interface of the Tank-Level Control Simulator

define the exiting piping system of the tank; instead, we simply chose a constant value for *K*.

c. The Digital PID Controller

A PID control algorithm is usually presented as an integral-differential equation [21]:

$$Q = K_p e(t) + K_I \int e(t)\,dt + K_D \frac{de}{dt} \tag{4}$$

where: Q is the controller's output which is the input flow rate; *e (t)* is the deviation between the actual tank level and the set point; K_p , K_I, and K_D are the proportional, integral, and derivative coefficients, respectively.

$$Q(n) = Q(n - 1) + K_1 e(n) + K_2 e(n - 1) + K_3 e(n - 2) \tag{5}$$

where: Q*(n)* is the flow rate to be determined by the controller; Q (*n-1*) is the flow rate of the previous sample cycle; *e(n)* is the tank level deviation from the current cycle; *e(n-1)* is the tank level deviation from the previous sample cycle; *e(n-2)* is the tank level deviation from the cycle before the previous; and k_1, k_2, k_3 are control constants derived from coefficients K_p , K_I , and K_D using the following relationships:

$$k_1 = K_p + K_I + K_D \tag{6}$$

$$k_2 = -K_p - 2K_D \tag{7}$$

$$k_3 = K_D \tag{8}$$

d. Control Performance Measurement

The performance of the control system is evaluated with four measures: *rising time* (t_r), *settling time* (t_s), and *percentage overshoot*

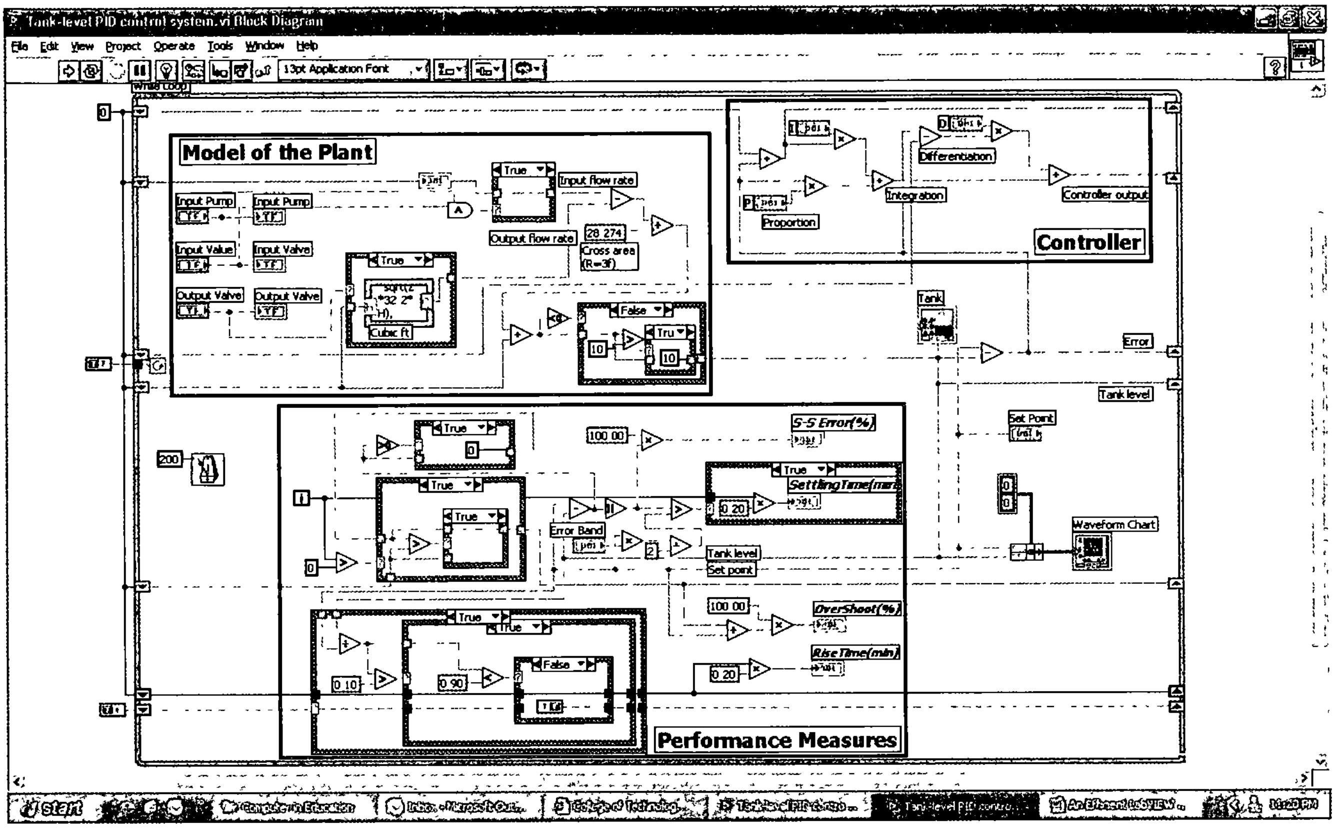

Figure 2. The LabVIEW diagram of the simulator consisting three major units: the tank model, the controller, and the performance evaluating unit.

(*P.O.*) are used to measure the system transient response and *steady state error* (*SSE*) is used to measure the system steady response. The LabVIEW diagram (shown in Figure 2) was designed in a way that all these four performance measures can be calculated in real time. This information is then immediately updated in the user interface in Figure 1.

The PowerPoint Presentation

The second important component of the teaching module is the *PowerPoint presentation.* To make it a stand-alone delivery module, topics introduced in the module include: basic feedback control concepts, PID control modes, PID parameter tuning, and general design strategy. All these items are presented concisely without overwhelming mathematical derivation. The introduction is outlined with brief descriptions of each topic in the following paragraphs.

a. Feedback Control Basics

The basics for feedback control include a simple block diagram and the control performance measures using a system's step response. A simple block diagram (see Figure 3) helps the students understand a set of feedback control concepts and the relationships among them: control plant, set point, actual output, error (deviation), control law. These concepts are given in the context of a practical application such as room temperature (air conditioning) or automobile speed control.

Control performance measures, as described previously, are then introduced with a plot for the step response of a typical second-order system (see Figure 4). The four performance measures follow the definitions in [21].

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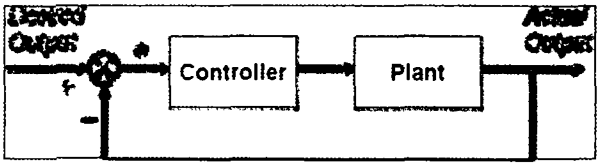


Figure 3. Block diagram of a control system.

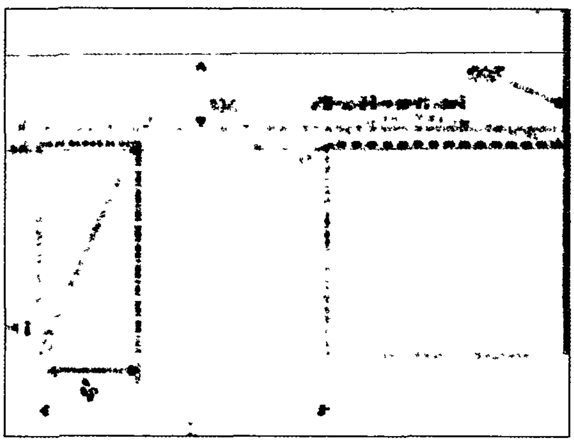


Figure 4. Performance measures with a typical step response.

b. PID Control

The meaning of the term "PID" is first explained to help students make connections between controls and mathematics. The history [2] and broad applications of this classical control law [1] are reviewed. After that, the mathematical implications of each component are further detailed as contributions of the three basic control components: Proportional, Integral, and Derivative. Each is explained in terms of the deviation of the actual output from the set point, as shown:

$$Q_p = Kp\, e(t) \tag{9}$$

$$Q_I = K_I \int_0^t e(\tau)\, d\tau \tag{10}$$

$$Q_d = K_D \frac{de}{dt} \tag{11}$$

To better explain each of these control components, a couple of techniques are used: a) bring in a control component with a practical application that requires this component's contribution to the performance, and b) intuitively explain each control component's effect on the controller's output. Table 1 summarizes the applications used to introduce each component and the intuitive explanation of the component's effect on the system performance. As an example, missile control is used to start the discussion of integral control. In this application, the missile has to hit the target; existence of any steady-state-error will cause the missile to fail this goal. Integral control is therefore introduced to eliminate the stead-state-error and meet the application needs. Please note that the examples are for intuitive "illustration" purpose and description may not be completely strict.

After studying all the three control components, and explaining how to they are applied in different situations, PID parameter tuning is summed up with general guidelines (Table I): make tradeoffs between all the performance measures and make the system as simple as possible.

Table I.
TECHNIQUES USED FOR CONTROL COMPONENT EXPLANATION

	Application	Requirements	Intuitive effect
P	Room temperature control	Usually no special requirement. Cost is the top concern, which requires the system to be simple.	The output of the controller is proportional to the deviation
I	Missile control	The goal of the missile is to hit the target; i.e., no steady-state-error is allowed	Integral control adds a "memorization" effect to the output of the controller and eliminates steady-state-error
D	Automobile speed	For passenger's comfortableness, speed fluctuation is not acceptable. i.e., overshoot should be avoided.	Derivative control adds a "prediction" of the future change of the deviation and therefore stabilizes the system.

Integration of the Simulation and Presentation

When delivering the control modes, PowerPoint slide lecturing is integrated with LabVIEW simulation as illustrated by the flowchart in Figure 5. In PowerPoint slides, each mode is first brought in with an application need as described earlier; LabVIEW simulation is conducted to demonstrate how each control mode meets the needs. The simulation results are then recorded in a table (See Table III) so that all the performance measures for the three modes can be compared side-by-side to help students see the contributions of different control components (i.e., P, I, and D).

When running the simulation, the control performance display chart on the graphical user interface in Figure 1 helps to compare the performance of the system with different combinations of control coefficients, because the chart can display multiple simulation results in the same window. Figure 6 shows simulation results from three sets of control coefficients, where all the cases have $K_p = 10$, $K_I = 10$, and the derivative coefficient $K_D = 0$, 1, and 5, respectively for the three cases. The corresponding overshoots are 53.2%, 46.7%, 40.8%. This figure visually compares the overshoots and enhances students' cognition and understanding of the fact that a strong derivative component of a PID controller typically decreases the system overshoot.

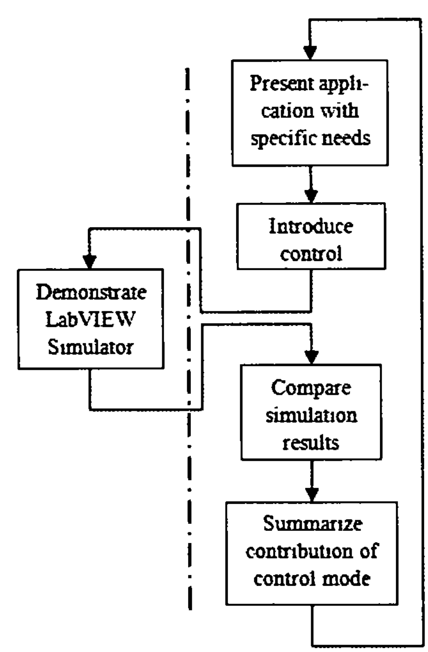


Figure 5. Integration of simulation with PowerPoint Lecturing.

TABLE III.
COMPARISON OF PERFORMANCE MEASURES WITH DIFFERENT CONTROL COEFFICIENT COMBINATIONS

	P			PI			PID		
k_p	5	10	20	10	10	10	10	10	10
k_i	0	0	0	0.5	0.75	1	0.75	0.75	0.75
k_d	0	0	0	0	0	0	2	5	15
t_r (min)	2.6	1	0.2	0.8	0.6	0.4	0.6	0.8	0.8
t_s (min)	Inf.	2	0.6	7	7.8	8.2	6	5.8	5.4
M_p (%)	0	0	0	8.3	12	15	11	11	10
SSE (ft)	3.2	1.6	0.8	0	0	0	0	0	0

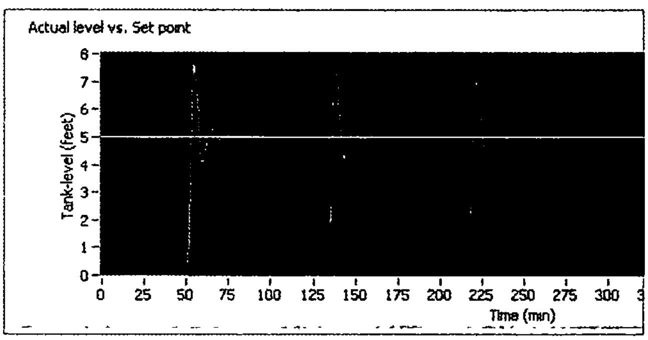


Figure 6. Comparison of overshoots from PID controllers with different derivative components.

Progressive Learn by Doing

Since programming with LabVIEW is straightforward, one additional teaching technique that can be used with the module is to have the students implement the controllers with LabVIEW after presenting the three PID components. The students may start with a simple manually controlled tank-level system (see Figure 7) to acquire the needed LabVIEW skills. This also increases their understanding of the dynamic characteristic of a tank system. Then the students move into more advanced P, PI, and PID controllers progressively. After this learn by doing experience, the students gain good understanding of the combinations of the control modes.

Results

To date, we have used this PID education module for two different purposes: one was to teach high school students; the other to teach seniors in a general engineering program. In both cases, the delivery was received well and students were able to understand most of the PID concepts within a very limited time.

High School Outreach

In 2006 summer, we applied this module to North Carolina Summer Ventures in Mathematics and Science to expose high school students with engineering and the application of mathematics in engineering. During the first three weeks of this four-week program, PID control, along with 3D solid modeling and programming logic controllers, was used to introduce typical engineering topics. PID control with the proposed teaching module aimed to helping talented high school students understand applications of mathematics in the real world. The interleaving approach introduced earlier was first used to give the students the necessary feedback control background and present PID control modes. The students, after stepping through a simple manually-controlled tank level system, implemented a P, PI, and PID controller consecutively.

During the available time, all the 17 students were able to program LabVIEW VIs to complete all three functional controllers. One of the students was very interested in the mathematics behind PID and decided to explore more during the last week's independent research. After closely examining the provided LabVIEW program, he successfully converted the LabVIEW version of the PID controller into an Excel spreadsheet with macros. In the reflection session at the end of the program, some other students expressed their excitement about the fact that they had been able to learn and understand PID control at an advanced level, something they had never expected.

A survey conducted at the end of the program demonstrated that 88% of the students agreed that they have learned from this module. However, because this was the first time the module was used, close to half of the students expressed that they would benefit more if more LabVIEW instructions had been given. In addition, one student mentioned that the mathematics was difficult. We should note that these students are competitively selected and much more advanced than typical high school students.

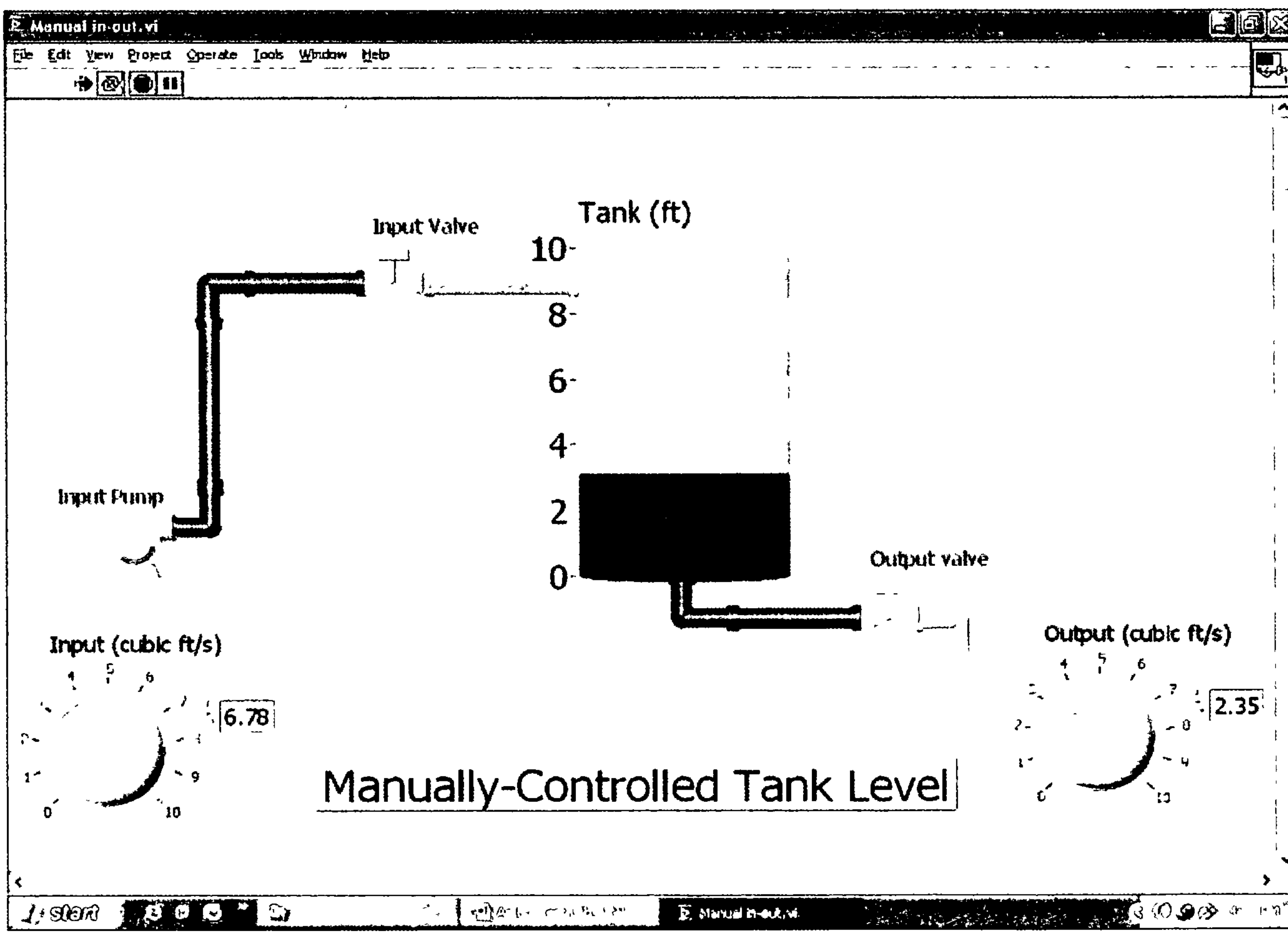


Figure 7. A manually control tank-level control system.

Teaching an Instrumentation and Control Course

In Fall 2007, this module was used in an *Instrumentation and Controls* course (senior undergraduate course) in a general engineering curriculum at East Carolina University [22]. As its name suggests, this course aims to providing students with basic concepts on the two topic areas: *instrumentation* and *controls*. The PID control teaching module was used after the introduction of all the basic feedback control concepts (transform functions, system performance, and stability, etc). A fifty-minute lecture was used to teach PID with this module. Because the students all had the necessary calculus background, the visualization of the tank system and intuitive explanation of each component made the abstract mathematical material easier and deepened their understanding of integrals and differentiations. The students got an average of 94% for a question on PID control in the final exam, demonstrating that the students received the material well in spite of the limited time spent on the topic.

Discussion

The two examples demonstrated different application possibilities of the module: the Summer Ventures activity allowed high school students to see how mathematics are applied to real-world problems and made calculus accessible to those have no prior knowledge; the use of the module in the *Instrumentation and Control* course, on the other hand, visualized the control concepts that had been derived in mathematics and provided substantial insights of the control schemes originally presented in differential equations. Results from the two applications showed preliminary success of using the proposed module to deliver PID controls. Compared to physical experiments, the simulation requires no cost on equipment and much less time to complete. In addition to the efficient coverage of PID control, the learn-by-doing approach utilized with the module adds a side benefit: it exposes the students with LabVIEW, a popular software package that engineering graduates are very likely to see in their future.

There are several opportunities to extend the applications of this teaching module. For example, the module can be used along with Ziegler-Nichols method to provide a systematic way to tune P, I, D coefficients and give students more insights in the control algorithms. Furthermore, because the module does not require physical equipment, it can be conveniently migrated from face-to-face instruction to distance education. The web-based laboratory model allows the students to interactively change the control coefficients and control modes, observe dynamic changes, and compare simulation results. This interactive and repeatable virtual laboratory provides students with more flexibility and should promote student-centric learning.

Conclusions

This paper presented a PID control teaching module. The strategically integrated module combines visualization, intuitive explanation, and learn-by-doing pedagogical methods and provides a time/cost efficient solution to teach feedback control and PID control related topics. Two application experiences have shown that the module can actively engage students and enhance students learning. Further integration of other PID coefficient tuning approaches and web-based extension can make the module better serve other teaching environments.

References

1. K. J. Astrom and T. Hagglund, "New tuning methods for PID controllers," presented at European Control Conference, Rome, Italy, 1995.

2. N. Minorsky, "Directional stability of automatically steered bodies," *Journal of American Society of Naval Engineering*, vol. 34,, pp. 280-309, 1922.

3. P. C. Wankat and F. S. Oreovicz, "Teaching Engineering," 1993.

4. J. Yao, L. Limberis, and P. Kauffman, "An Electrical Systems Course in a General Engineering Program: Experience and Lessons," presented at Annual American Society of Engineering Education Conference, Hawaii, USA, 2007.

5. J. Yao and L. Limberis, "A Project-Driven Approach to Teaching Controls in a General Engineering Program," presented at 2008 Annual American Society of Engineering Education Conference, Pittsburg, MA, USA, 2008.

6. D. Gillet, H. A. Latchman, C. H. Salzmann, and O. D. Crisalle, "Hands-on laboratory experiments in flexible and distance learning," *J. Eng. Educ.*, vol. 90, pp. 187-191, 2001.

7. W. G. Hurley and C. K. Lee, "Development, implementation, and assessment of a web-based power electronics laboratory," *IEEE Trans. Educ.*, vol. 48, pp. 567-573, 2005.

8. B. Wittenmark, H. Haglund, and M. Johansson, "Dynamic pictures and interactive learning," *IEEE Control Syst. Mag*, vol. 18, pp. 26-32, 1998.

9. M. de Magistris, "A MATLAB-based virtual laboratory for teaching introductory quasi-stationary electromagnetics," *IEEE Trans. Educ*, vol. 48, pp. 81-88, 2005.

10. J. Campbell, J. Bourne, P. J. Mosterman, and A. J. Brodersen, "The effectiveness of learning simulations for electronic laboratories," *IEEE Transactions on Education*, vol. 91, pp. 81-87, 2002.

11. H. Hodge, H. S. Hinton, and M. Lightner, "Virtual circuit laboratory," *J. Eng. Educ.*, pp. 507-511, 2001.

12. M. D. Koretsky, D. Amatore, C. Barnes, and S. Kimura, "Enhancement of Student Learning in Experimental Design Using a Virtual Laboratory," *IEEE Transactions on Education*, vol. 51, pp. 76-85, 2008.

13. M. C. M. Teixeira, E. Assuncao, and M. R. Covacic, "Proportional Controllers: Direct Method for Stability Analysis and MATLAB Implementation," *IEEE Transactions on Education*, vol. 50, pp. 74 - 78, 2007.

14. I. Branica, I. Petrovic, and N. Peric, "Toolkit for PID dominant pole design," *9th International Conference on Circuits and Systems Electronics*, vol. 3, pp. 1247 - 1250, 2002.

15. U. Yolac and T. Yalcinoz, "Comparison of fuzzy logic and PID controllers for TCSC using Matlab," presented at 39th International Universities Power Engineering Conference 2004, 2004.

16. T. Matsuo, R. Yoshino, H. Suemitsu, and K. Nakano, "Nominal performance recovery by PID+Q controller and its application to antisway control of crane lifter with visual feedback," *IEEE Transactions on Control Systems Technology*, vol. 12, pp. 156 - 166, 2004.

17. M. Johansson, M. Gafvert, and K. J. Astrom, "Interactive tools for education in automatic control," *IEEE Control Syst. Mag.*, vol. 18, pp. 33-40, 1998.

18. S. G. Crutchfield and W. J. Rugh, "Interactive learning for signals, systems, and control," *IEEE Control Syst. Mag*, vol. 18, pp. 88-91, 1998.

19. J. S. Lee and D. R. Yang, "Chemical engineering education using Internet," presented at Proc. 8th APCChE Congress, Seoul, Korea, 1999.

20. LabVIEW. http://www.ni.com/labview/.

21. R. C. Dorf and R. H. Bishop, *Modern Control System*, 10 ed: Prentice Hall, 2005.

22. P. Kauffmann, R. Rogers, and P. Lunsford, "A Case Study: Development of a Practice Oriented Engineering Program with Implications for Regional Economic Development," presented at ASEE Annual Conference, 2004.

Biographical Information

Dr. Jianchu (Jason) Yao joined the Department of Engineering at East Carolina University as an Assistant Professor in August, 2005. He received B.S. and M.S. degrees in electrical engineering from Shaanxi university of Science and Technology, China, in 1992 and 1995, respectively, and the Ph.D. degree in electrical engineering from Kansas State University in 2005. His research interests include wearable medical devices, telehealthcare, bioinstrumentation, control systems, and biosignal processing. His educational research interests are laboratory/project-driven learning and integration of research into undergraduate education. Dr. Yao is a member of the American Society of Engineering Education and a senior member of Institute of Electrical and Electronics Engineers.

Loren Limberis, PhD, is an Assistant Professor in the Department of Engineering at East Carolina University. He earned his B.S. in electrical engineering and Ph.D. in bioengineering from the University of Utah. Dr. Limberis was a research analyst with Southwest Research Institute prior to his academic career. His research interests focus on designing techniques to utilize nature's highly complex and sophisticated biological systems to develop biohybrid devices for use in biotechnology applications.

Rick Williams, PhD, is an Assistant Professor in the Department of Engineering at East Carolina University. He earned his B.S. and M.S. in mechanical engineering from Georgia Institute of Technology and his Ph.D. in mechanical engineering from Auburn University. Prior to receiving his Ph.D., Williams was a submarine office in the U.S. Navy and worked in industry as an engineer for Corning, Inc. Dr. Williams' research interests include the integration rapid prototyping with composites to fabricate composite sandwich structures and developing novel pedagogical approaches within engineering education.

William E. Howard is an Assistant Professor in the Department of Engineering at East Carolina University. He holds a B.S. in civil engineering and an M.S. in engineering mechanics, both from Virginia Tech, and a Ph.D. in mechanical engineering from Marquette University. He spent 14 years as a design and project engineer before beginning his academic career at Milwaukee School of Engineering, where he was a faculty member for nine years. His research interests include composite materials and engineering education.

THE INERTIAL NAVIGATION UNIT: TEACHING NAVIGATION PRINCIPLES USING A CUSTOM DESIGNED SENSOR PACKAGE

Joe Bradshaw, CAPT J.W. Nicholson
U. S. Naval Academy

Abstract

This paper describes the application and design of a small, inexpensive inertial navigation unit (INU) created to introduce systems engineering students at the United States Naval Academy (USNA) to the principles of navigation systems and to act as a navigation sensor for robotic and autonomous vehicle projects. The INU has been used in place of a multitude of standard navigation sensors such as an inertial measurement unit (IMU), magnetic compass module, and Global Positioning System (GPS) receiver. Its integrated design simplifies mechanical mounting, reduces navigation system weight and size, simplifies data interfacing with a control computer, and provides great flexibility for reconfiguring to meet a variety of engineering education objectives. The INU is capable of firmware upgrades and algorithm enhancements in the field via in-circuit programming, enhancing its longevity as a useful educational tool. In addition, a variety of controllers or a personal computer (PC) can communicate with the INU board through a standard RS-232C serial interface. This compact unit provides good system performance at a reasonable cost compared to most commercially available units. These features enable hands-on education techniques in the navigation aspects of robotics, examples of which are presented.

Introduction

A significant amount of work in robotics is done in the USNA Systems Engineering Department, with autonomous vehicles in particular. Such ABET accredited engineering programs require a "capstone" design project for graduation, and each year there are numerous student projects to build autonomous vehicles of various types. Several student independent research projects are also completed each year. Supporting these projects is a senior-level elective course in autonomous vehicles in which students are exposed to the principles of vehicle navigation and provided hands-on experience with navigation system components. Navigation systems commonly include an IMU, a combination of accelerometers and gyros to sense vehicle translational and rotational motions without external reference. Other navigation components commonly found on autonomous vehicles include a magnetic compass as a heading reference and a GPS receiver for position and velocity measurement. The need for small and inexpensive, yet capable, navigation systems in this department are therefore necessary.

To meet this need, a navigation sensor package was developed and built "in house". A printed circuit board was manufactured locally and populated with readily available components to produce a compact, low-cost inertial sensor module that meets these requirements in all but a few of the most demanding applications. The INU is based on Microchip's dsPIC30F4013 digital signal processor[1] and commercially available sensors. The INU is less than 2" x 3" x 1.3", weighs less than 1.6oz, costs under $300 for parts, and has an update rate of 80Hz. The system provides 6-axes of inertial sensor data, GPS, a real time clock (RTC) for data stamping, magnetic compass, and temperature sensing, making it an ideal circuit board for embedded applications. The system integrates analog and digital sensors, serial communication interfaces and protocols, and a user command interface.

In this work we outline the development of a digital signal processor-based navigation system and describe its capabilities. We also describe its application in student work, particularly as the basis of laboratory experiments in a course on autonomous vehicles.

System Description

Our research combines low cost readily available components to provide a sensor system capable of improving embedded computing applications and enhancing laboratory experimentation. The dsPIC Inertial Navigation Unit (Figure 1) acquires and processes various sensor data to be transmitted to an external control unit such as a microprocessor board or PC, for purposes of state estimation and navigation. The navigation system can be configured by the external control unit to meet the user application and to provide a high-level of sensor information.

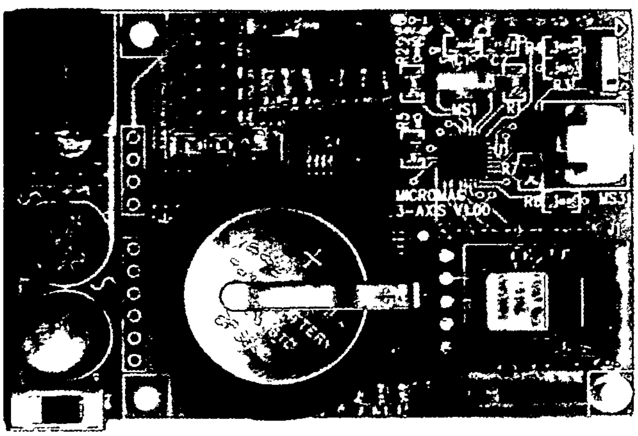


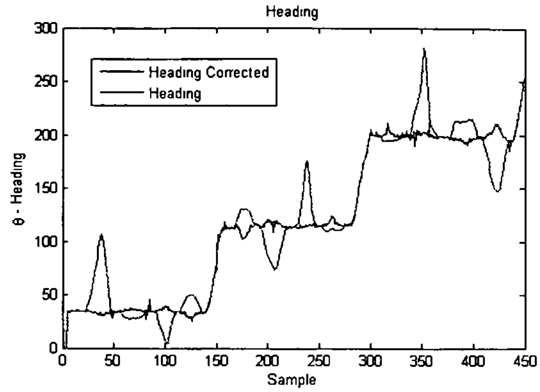
Figure 1 – A top view of the complete Inertial Navigation Unit. The three Analog Device's ADXRS300 gyros, MicroMag3 magnetometer, 3 volt backup battery, power supply, and communications port are visible.

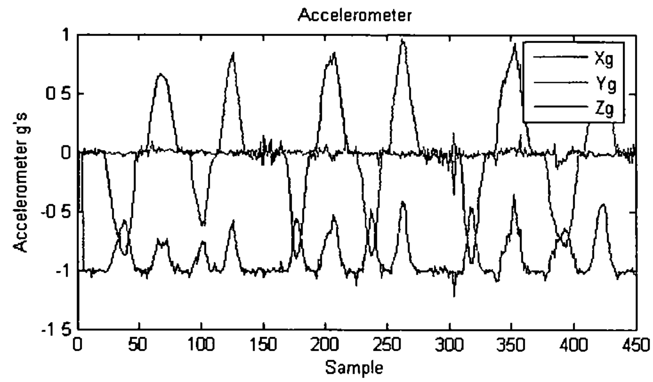
Hardware Description

The dsPIC Inertial Navigation Unit (INU) utilizes a Microchip dsPIC30F4013 digital signal processor to gather sensory data from analog and digital sensors for purposes of state estimation and to improve control system capability in the area of navigation. The circuit board is equipped with 3-axes of acceleration measurement from an MMA7260Q micro-machined accelerometer from Freescale™ Semiconductor. Roll, pitch, and yaw rates are measured with 3 Analog Devices ADXRS300 rate gyroscopes with internal signal conditioning. A MicroMag3 3-axis magnetic field sensor module is used as a digital compass for heading indication. Also implemented is a Trimble Lassen® iQ 12-channel GPS receiver with an on-board backup battery. A National Semiconductors LM34 or LM35 precision temperature sensor allows for precise temperature measurement and calibration of analog sensors under varying environmental conditions. Data is gathered and transmitted serially by the dsPIC30F4013 at 115200 8N1 baud rate by means of the level-shifted serial port at an update rate of 80Hz in the standard North-East-Down coordinate frame convention. The serial port can also be placed in a command mode. A Dallas Semiconductor DS1390 SPI interface RTC is used to time stamp data and aid in special event recording. Four independent voltage regulators are used to separate analog from digital supplies, aiding in digital noise isolation from inertial analog sensor circuits. The populated circuit board weighs 1.370oz without the GPS antenna (version 1.1 containing the power connector, fuse, bridge rectifier and switch weighs 1.585oz).

The MMA7260Q accelerometer on the INU employs an on-board single pole switch capacitor filter, temperature compensation, and g-select pins for output sensitivity selection of 1.5g/2g/4g/6g. The accelerometer has a low current consumption of 500μA and runs from a 3.3V regulator. The accelerometer is used for detecting the angle of the INU with respect to gravity by calculating the arc-sine of its X and Y g-measurements. A single pole digital low-pass filter is also used on output calculations to reduce accelerometer bandwidth response in tilt measurement. The low-pass recursive filter constants are calculated from the cutoff frequency using calculations derived from "The Scientist and Engineer's Guide to Digital Signal Processing[2]." The accelerometer should be placed as close to the center of rotation of the system being measured as possible to keep rotational influences on the accelerometer at a minimum.

A Precision Navigation Instruments MicroMag3 magnetic field sensing module[3] shown in Figure 1 is used to derive magnetic north from the Earths magnetic field. The module uses a serial peripheral interface (SPI) full duplex synchronous serial port communications protocol. The dsPIC30F4013s SPI port is configured for an 890KHz clock rate in 8-bit mode. Each axis of the sensors output is a measurement in micro-Tesla (μT) and depends on the gain set by 3 period select bits in the control word. These bits determine the number of counts per μT effectively scaling the resolution of the sensor axis to be measured. After the command word that determines the resolution and axis is transmitted to the MicroMag3, a delay ranging from 340μs at the lowest resolution (L/R 32 division ratio) to 28.65ms at the highest resolution (L/R 4096 division ratio) is employed followed by a Data Ready Line (DRDY) going to a high state. An external interrupt is used on the DRDY line so the dsPIC still processes data during compass measurement acquisition and only spends approximately 23μs reading the result and giving a new command word for the next axis to read. The application of this DRDY line on an external interrupt greatly increases the overall throughput of the INU. Two compass values can be transmitted in the data string. The first is the calculated value using low-pass filtered accelerometer measurements to determine instantaneous roll and pitch angles. These angular measurements are applied to magnetic compass measurements and use a rotational transformation to translate compass values to the horizontal plane, correcting for induced angular error[4]. The second compass measurement is the arc-tangent of raw Y over X magnetic measurements and will have an error relative to the tilt angle with respect to the horizontal plane. This compass value, however, is not influenced by accelerometer measurements (Graph 1).





Graph 1 – Graph of the accelerometer corrected heading vs. raw magnetic heading with applied angular rotation (samples taken at approximately 16 milliseconds).

Analog devices ADXRS300 rate gyros[5] were chosen for rotational rate information due to their small size, relatively low cost (less then $40 ea.), availability, and reliability. The gyros output an analog voltage directly proportional to angular rate in deg/sec (5mV/deg/sec) applied normal to the top surface of the BGA (Ball Grid Array) package. Roll and pitch gyro boards are mounted perpendicular to each other and vertical to the top surface of the INU board. The yaw gyroscope is mounted horizontal to the INU board directly over the accelerometer.

A Trimble Lassen® iQ GPS module[6] was chosen for its size and availability. The GPS module initializes in Trimbles proprietary TSIP mode, which is a binary serial protocol. The module is placed in NMEA-0183 mode through a series of commands and will retain an almanac for satellites with a backup battery once acquired. The module is capable of tracking up to 12 satellites and uses an external active antenna. GPS data is updated at a rate of 1Hz when available.

A DS1390 Trickle-Charge Timekeeping Chip[7] from Dallas/Maxim is used as a RTC for the INU. The date and time can be set to time stamp transmitted data for accurate recording to the hundredths of a second. The DS1390 uses a variation of SPI communications bus and needs to be configured appropriately before data transfers.

The dsPIC uses a 12-bit Successive Approximation converter running in channel scan interrupt mode updating all 13 analog channels every 142.8uS (7.003KHz). The dsPIC30F4013 Timer3 period register is set up to match after 12.5ms. When the Timer3 interrupt flag is set and 12.5ms has elapsed, the most current data is used in inertial/spatial calculations and the resulting information is transmitted serially in NMEA ASCII format: "$DSPNB," header, the corrected compass value, uncorrected compass value, X-axis, Y-axis, and Z-axis acceleration in g's, roll rate, pitch rate, and yaw rate in deg/sec, latitude data, longitude data, the current time, temperature in degrees, the current sample number, and an asterisk (*) followed by the hexadecimal checksum of all the characters in the string before the asterisk, a carriage return (0x0d, '\r') and a linefeed character (0x0a, '\n'). All the components in the data string are comma delimited. Each parameter can be individually turned on or off through a command set interpreted by the dsPIC processor. Commands are sent as ASCII strings to the dsPIC30F4013 Navigation Unit and are executed upon the reception of a carriage return. The board can also be placed in a command mode upon which the processor requires a single carriage return before transmitting the data.

Software Description

The dsPIC® 30F4013 microcontroller from Microchip is programmed using Microchips MPLAB® Integrated Development Environment with the C30 full-featured ANSI compliant C compiler. The microcontroller can be reprogrammed in the circuit via ISP (In-circuit Serial Programming) connector. This allows for future firmware updates and software expandability.

Upon power-up or hardware reset the microcontroller program initializes variables and configures the hardware peripherals such as the general purpose I/O pins, the SPI communications port, two serial ports, and the analog-to-digital converter. Then the program enters an endless software loop which checks for serial commands, processes analog (rate gyros, accelerometers, temperature) and digital (MicroMag3 compass, GPS, RTC) sensor information. Analog to digital converter values are converted to voltages, then corresponding output parameters. Gyros output °/sec rate, accelerometers output volts/gravitational g measurement. Individual output parameters can be turned on and off through a serial command interface. These parameters are then individually concatenated to a string of ASCII characters and transmitted serially to the external control unit. The serial command interface also provides provisions for setting the RTC, and recalibrating the offsets for the inertial sensors.

Several microcontroller peripherals are modularly broken up into interrupts, such as the analog-to-digital converter scan interrupt, MicroMag3 compass data ready line external interrupt, the serial communications port character reception interrupt, and the GPS module character reception interrupt. Using interrupts to control certain functions increased the overall throughput and simplified software task management of the system.

Performance in the Lab

Along with successful application in autonomous vehicles, the INU has been used in the ES456 autonomous vehicles course as the basis of an IMU laboratory. In the lab it is used to familiarize students with accelerometer and gyro sensors and to demonstrate the mathematical principles in navigation algorithms. In this laboratory is it configured as an IMU, without the need for the compass and GPS hardware. The INU is used in conjunction with a 3-axis rotational gimbal locally constructed of PVC plastic (Figure 2).

The lab uses the Windows HyperTerminal program to communicate with the INU through the PCs RS-232C serial COM port. Students type commands and receive data through a basic textual interface which is augmented at times with a text capture file. Once HyperTerminal is correctly set up for the INU serial protocol (115200 baud, 8N1) and power is applied to the board, striking the "Enter" key returns a single line of data in NMEA-0183 text format consisting of comma-separated measurements from all three sets of accelerometers and gyros, followed by a checksum. Initially, students make some general observations of accelerometer measurements by changing the INU attitude and eventually identify the orientation of its 3 axes. As the lab uses only the accelerometers and gyros for data analysis, other data fields for other navigation sensors are disabled. This is done by initially issuing the "ALLOFF\r" command, then enabling the individual X, Y, and Z accelerometers by issuing the "XGON\r", "YGON\r", and "ZGON\r" commands respectively.

Once accelerometer axes are identified and sketched, students can align the INU with the PVC rotational gimbals roll, pitch, and yaw axes in the North-East-Down convention with roll around the X-axis. Once mounted, the gimbals are used to input specific Euler angles and students can apply their knowledge of coordinate transformations to predict the

Figure 2 – The INU positioned on the PVC rotational gimbals in the lab.

rotation of the gravity vector from the global frame to the IMU body-fixed frame. The inverse can also be performed, allowing students to compute static vehicle attitude by sensing of gravity components with the 3 INU accelerometers and calculating the Euler angles.

Although gravity is a convenient and quantified input to the INU accelerometers, there is currently no such convenient input to the INU rate gyros. Instead, integration of gyro rate is used by rotating through a known angle to demonstrate gyro principles. As the INU is rotated through a known angle, its rate measurements are sent both to the computer screen as well as to a text capture file. The captured rate data is then exported to a spreadsheet where it is numerically integrated. Comparing the integrated rate data to the known angle of rotation allows evaluation of the global rotational velocity vector as rotated into the body-fixed frame of the INU. For example, when the INU is level and rotated 180° about the gimbals vertical axis, the Z gyro integrated angular rate is approximately 180° and the integrated rates of the other gyros are approximately zero. However, inserting a pitch or roll angle into the gimbals reduces the Z gyros rate while increasing the X or Y gyros rate respectively.

In another lab, the INU is used to teach students rudimentary Kalman filtering of sensor data. In this lab both gyro data, which is subject to drift error, and compass data, which is subject to magnetic anomalies, are filtered to provide an estimate of heading.

Conclusions and Future Work

In future work numerous enhancements can be made on this navigation unit. A few improvements presently underway include the application of a discrete Kalman filter[8] on the output data to provide optimal state estimation[9]. A motorized gyroscopic test platform is currently being developed to provide continuous yaw axis rotation and +/- 90 degrees of pitch and roll rotation for rate gyro testing. Such an apparatus would aid in quantitative data collection from the INU for statistical parameter acquisition, enabling enhanced algorithms and on-board program calculations. Presently a MATLAB program capable of displaying the INU motion real time and graphing sensor data has been written for demonstration and preliminary data analysis. Work is also being done to incorporate a software complementary filter on the accelerometer and gyro measurements.

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Bibliography

1. Microchip Technology Inc., dsPIC30F3014/ 4013 Data Sheet (1/30/2007), ONLINE: http://ww1.microchip.com/downloads/en/DeviceDoc/70138E.pdf, Accessed 10 January 2008

2. Steven W. Smith, "The Scientist and Engineer's Guide to Digital Signal Processing", (California Technical Publishing, 1997)

3. PNI Corporation., MicroMag3 Data Sheet_June 2006 , ONLINE: https://www.pnicorp.com/downloadResource/cMM3s/datasheets/110/MicroMag3+3-Axis+Sensor+Module_June+2006.pdf, Accessed 10 January 2008

4. M.J. Caruso, "Applications of Magnetic Sensors for Low Cost Compass Systems", Honeywell, SSEC

5. Analog Devices., ADXRS300 Data Sheet (3/2004), ONLINE: http://www.analog.com/UploadedFiles/Data_Sheets/ADXRS300.pdf, Accessed 16 January 2008

6. Trimble, Lassen® iQ module Datasheet, ONLINE: http://trl.trimble.com/docushare/dsweb/Get/Document-338501/Lassen%20iQ_Reference%20Manual_Rev%20B_April%202005.pdf, Accessed 16 January 2008

7. Dallas Semiconductor/Maxim, DS1390 Timekeeping Chip Datasheet, ONLINE: http://datasheets.maxim-ic.com/en/ds/DS1390-DS1393.pdf, , Accessed 16 January 2008

8. Robert Grover Brown and Patrick Y.C. Hwang, "Introduction to Random Signals and Aplied Kalman Filtering", (John Wiley & Sons, Inc., 1997)

9. Arthur Gelb (Editor), "Applied Optimal Estimation", (The Analytic Sciences Corporation, 1974).

Biographical Information

Joseph Bradshaw has been an Electronics Technician at the U.S. Naval Academy for the Weapons and Systems Engineering Department for 8 years. His interests are in the design of special hardware and development of software for projects and labs.

Captain Jack Nicholson is the Associate Chair and a Permanent Military Professor in the Weapons and Systems Engineering Department. He heads the Naval Academy's Autonomous Underwater Vehicle Team and was a developer of the Naval Academy's autonomous vehicles course.

DEVELOPING ACADEMIC SOFTWARE FOR TEACHING TIME SERIES ANALYSIS: A CASE STUDY

Julio Cañón
Department of Hydrology and Water Resources and SAHRA
The University of Arizona
Tucson, Az, 85721.
Grupo GAIA, Universidad de Antioquia, Medellín, Colombia

Juan Valdes
Civil Engineering and Engineering Mechanics and SAHRA
The University of Arizona
Tucson, Az, 85721

Javier Gonzalez
Universidad de Castilla La Mancha,
Avda. Camilo José Cela, s/n 13071,
Ciudad Real, Spain

Abstract

The academic training on time series analysis requires not only a sound theoretical background on the methods but also the use of specific academic software to appreciate the methods' capabilities, limitations and proper applicability. It is desirable for students to program the routines and algorithms by themselves but this is not always feasible, particularly during short courses and workshops in which the interest is to understand the information supplied by several analytical methods. Considering the time constraints and the need to stress the interpretative rather than the computational skills, the authors have developed the software package UATSA (University of Arizona Time Series Analysis) that incorporates many analytical tools commonly used in time series analysis in an organized and sequential manner: exploratory statistics, markovian processes, univariate and multivariate analyses (ARMA models), frequency decomposition algorithms, principal components, canonical correlations and cluster analyses are included within the current version of the package. UATSA is a stand-alone executable file compiled in MATLAB® that has been used in courses of time series analysis in hydrology at the University of Arizona and in several workshops offered by the authors between 2004 and 2007. The software aims to easily illustrate the use of algorithms in the synthesis and decomposition of time series, providing a background to the methods and a visual platform that is user friendly and data extensive. The software has evolved through the years, incorporating suggestions made by students to improve its appearance and widen its scope. The software also has contributed to a shift in teaching dynamics by allowing students and instructors to focus on interpreting and analyzing outcomes rather than just learning the set of mathematical tools.

Introduction

Time series play a fundamental role in virtually all sciences and technical fields of knowledge. Each discipline, according to its own needs and interests, has contributed to the development of a wide range of tools to analyze time series. Time Series Analysis (TSA) is an active field of research that specializes in the development and application of methods to tackle a variety of scientific issues related to time series datasets.

Universities regularly offer introductory and advanced graduate courses on TSA with contents that vary according to the requirements of specific groups. In introductory courses it is a common practice to include standard methods on the time and frequency domains and the spatial analysis of distributed univariate and multivariate time series.

The desirable goal of letting the students write their codes to gain a full understanding of the algorithms (particularly in advanced courses) is usually challenged be the following aspects: the course's time constraints; the fact that not all the students in a course group, which usually consists of people with diverse backgrounds and interests, are familiarized with mathematical methods or have the required programming skills to either manage existing libraries or write their own scripts; the large datasets that must be handled and the complexity of managing several methods to analyze and synthesize the information in short time. TSA courses, therefore, involve the use and development of software to speed up the learning process and increase the number of methods that can be covered during a regular semester. There are several software options, both commercial (i.e., MATLAB®, MATHEMATICA®, S and SAS®) and freeware (i.e., R, Octave), that include TSA libraries and allow users to run their own programs.

People who are interested in applying the methods to analyze their datasets but lack the skills or are simply short of time to program their own codes may look for alternative software toolkits that are rigorous in their algorithms and have an interface that is simple to use and sufficiently descriptive of the methods used (these aspects of software development are discussed by [1] in detail). Many toolkits that perform statistics and time series analysis with different scopes and varying degrees of complexity are already available on-line as public domain software. Examples of these kind of software are: TISEAN[2] for nonlinear analyses, SSA-MTM Toolkit for spectral analysis[3], extRemes[4] for the analysis of extreme events, ASTSA[5] for introductory methods on time series analysis, KSpectra toolkit[6] for spectral analysis and the free statistics and forecasting software[7] based on R libraries.

It is within this context that the authors have developed the public domain software UATSA (University of Arizona Time Series Analysis) intended mainly for instruction on the fundamentals of TSA in hydrology. This paper describes the structure of UATSA, briefly introduces the main technical aspects of its modules and discusses the authors' experience in using it as an aid in introductory TSA graduate courses and short workshops.

Package Structure

UATSA is an executable, stand-alone application compiled in MATLAB®[8]. The package requires only the installation of an additional interpreter file (MCRInstaller.exe) to read the compiled libraries in the end-user's computer (this interpreter works also for any other executable file compiled in MATLAB®). The decision to use MATLAB® was based on the author's own experience working with the computational and graphical capabilities of the software (that already includes many libraries on statistics and TSA), including the possibility to design and compile Graphical User Interfaces (GUIs) as stand-alone applications.

UATSA's modular, user-friendly interface provides quick numerical and visual results of several methods of time series analysis (in time, frequency and space domains) that are commonly taught in graduate introductory courses in hydrology. Each module consists of (figure 1): an interactive panel that displays the data and the plots generated during the analysis; a menu bar that includes options to manage files and graphs, run the methods and open the users' guide document (a hypertext that briefly introduces the methods employed and has a step-by-step description on how to work with data and save output files and figures); a tool bar (with features from the MATLAB® GUIDE editor) that includes tools to dynamically interact with the panel plots (i.e., data matching, dragging and zooming); additional windows that display specific figures which may be edited and saved directly by the user with a default editor bar provided by the MATLAB® compiler.

The modules, which are designed to work independently, follow a logical progression from exploratory data statistics to the formulation of stochastic models based on the analysis, decomposition and reconstruction of data's deterministic and stochastic components. The modular structure facilitates also the package upgrading and the inclusion of new tools and methods as they are considered in the course work. Currently the toolbox includes:

1. Exploratory data analysis: sample statistics, detrending, data augmentation and gap filling.
2. Analysis and synthesis in the time domain: univariate models (annual and seasonal) and multivariate models (annual and seasonal).
3. Analysis and synthesis in the frequency domain: spectral analysis, multichannel singular spectrum analysis and wavelets.
4. Analysis and synthesis in space/time domains: principal components, canonical correlation and clusters.
5. State-space models: Kalman filter.

A brief explanation of these modules follows (this paper does not focus on the theory behind the methods but includes references to sources that discuss each in detail).

Exploratory data analysis

The module on exploratory data analysis provides analytical tools and graphical outputs to examine the statistical structure of time series (Figure 1). Its aim is to familiarize users with powerful, yet simple tools to visualize and quantitatively characterize time series. As with all the modules, data can be either imported from ASCII files written in specified formats or directly pasted in a table created in the interactive panel. The module allows the analysis of both single and multiple data series which may have missing values. Users can choose among several plot options (histograms, autocorrelograms, periodograms, box whisker and phase state diagrams) to represent the data series.

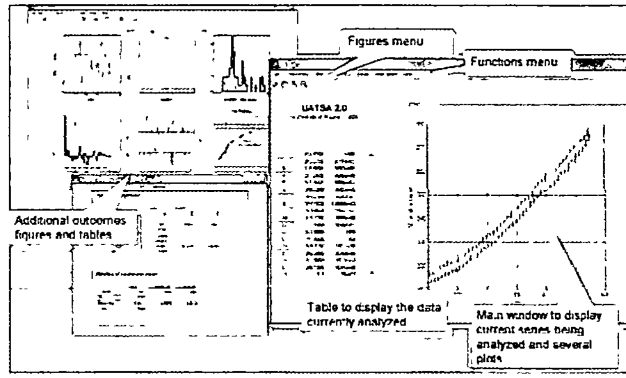


Figure 1. Home menu, interactive panel and some of the plots generated with the module of exploratory data analysis.

After a visual inspection, users may choose among several probability distribution functions to fit the data using the Kolmogorov-Smirnov confidence test as a criterion of acceptance or rejection[9]. A probability plot with the results of the test is generated in the main panel. Users can also detrend the data series using linear regression, differenciation and smoothing techniques (an option is provided to detrend the series with the module of analysis and synthesis in the frequency domain). The module provides also tools for data augmentation and gap filling using smoothing and cross correlation techniques for multiple time series.

Analysis in the time domain

Once the data's main features have been identified, users can proceed with the module on time domain analysis and synthesis (see Figure 2) which provides tools to visualize the autocorrelation functions (ACF) and partial ACF (PACF) for univariate and multivariate analysis to identify ARMA models and to generate annual and seasonal series[10]. Each analysis is divided in three main steps: 1) verification of normality and stationarity conditions, 2) determination of the ARMA model that best fit the observed data and

3) generation of synthetic series.

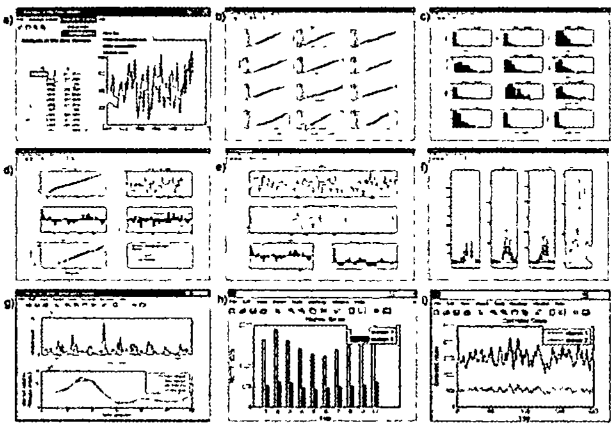


Figure 2. Univariate and multivariate analysis plots for generation of ARMA models: a) main module panel; b) normal plots; c) histograms; d) verification plots; e) generated series; f) multiple distributions; g) generated series and confidence intervals; h) multivariate series; i) generated correlated series.

Users must check first that series are normally distributed and stationary before choosing and running the appropriate ARMA model. For univariate annual analysis the module generates a window containing five plots (Figure 2d): the first two, representing the series and its distribution over a normal probability scale, serve to check the assumptions of normality and stationarity; the third and forth plots, representing the autocorrelograms of both the series and its residual after subtracting the ARMA component, and the fifth plot, representing the residual in a normal probability scale, help to determine what kind of autoregressive model better fits the data (i.e., the closer the residual values are to a normal distribution the better the model fits the series). If data are neither stationary nor normally distributed, users may subtract any significant trends and periodic components using either the exploratory module or the frequency domain module to obtain the residual series to work with.

Once the ARMA model that best fit the series has been identified, users can generate time series of any given length. The result is an output file containing the generated series and its statistical properties and a figure showing the generated and historical series and their respective autocorrelograms (Figure 2e). The subtracted trends and periodic components are presented in separate tables and their values must be added back to the generated series to obtain the representation of the whole process. For the annual multivariate case the module additionally generates a comparative bar plot of the multiple time series chosen (Figure 2h).

In addition to verify normality and stationarity conditions, seasonal analyses require users to define the probability distribution that best fits the seasonal data for every season considered (currently the module only incorporates normal and lognormal distributions). The module displays the generated time series as well as the mean seasonal values of both the observed and generated series bounded by a confidence region representing one standard deviation above and below the historical mean seasonal values (Figure 2g). Once the different distribution functions for all the seasons and series have been determined, users can generate correlated ARMA series. Users must review the results by comparing the generated and observed series and checking that first and second order statistical properties are preserved.

Analysis in the frequency domain

The module of analysis in the frequency domain aims at helping users identify, decompose and extract meaningful information from time series, such as trends and periodical components. It includes three mathematical tools: Fast Fourier Transform (FFT), Multichannel Singular Spectrum Analysis (MSSA) and wavelets.

Fast Fourier Transform (FFT)

The procedure is divided in four main steps: 1) frequency identification, 2) frequency decomposition, 3) extraction of significant components and 4) analysis of the residual. In the first step the module generates the FFT periodogram to identify significant frequencies in the series. In the second step, users choose the window length or embedding dimension to decompose the series in its main frequencies. The relative weights of these components (i.e., trends and periodicities) are represented by their eigenvalues plotted in descendent order (Figure 3a). W-correlations of the full decomposition eigenvalues are also depicted in a grayscale matrix from full correlation (black) to zero correlation (white) (Figure 3b). These graphs allow users to identify and choose significant components in terms of their correlation values.

In the third step users may extract and plot the significant components (i.e., trends and periodicities) that were previously decomposed. The module generates phase state plots of paired harmonics to refine the identification of those components of the spectrum that are in phase-quadrature (Figure 3c). A diagram shows the power spectrum of each selected component. In the fourth step, users subtract those previously identified significant components to obtain a residual series which is supposed to represent a random process. The module generates a plot that superimposes the sum of significant components to the original series and plots also the residual series and its spectrum (Figure 3d). Users may repeat the process over the residual series until it exhibits no significant frequencies in its power spectrum.

Multichannel Singular Spectrum Analysis (MSSA)

MSSA is a data-adaptive, nonparametric technique that allows the analysis of multiple signals (channels) simultaneously and the extraction of their common significant trends and oscillations[3, 11-13] (the analysis of single series is known simply as SSA). The procedure

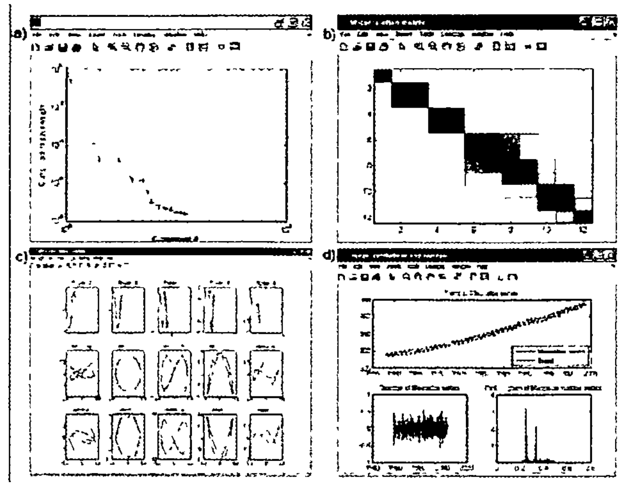
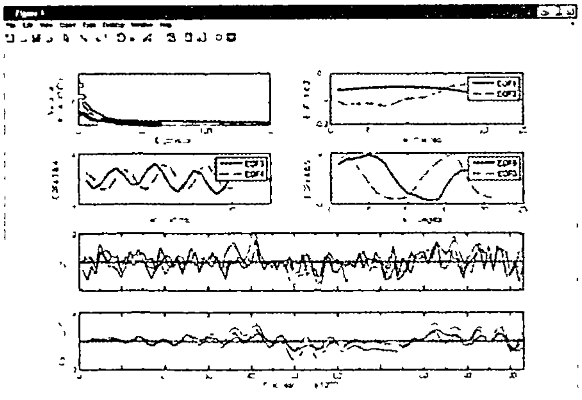


Figure 3. Example of plots displayed in the spectral analysis using FFT: a) eigenvalue decomposition, b) w-correlation matrix, c) phase-state diagrams of selected frequencies and d) reconstruction of trends and oscillations and residual periodogram.

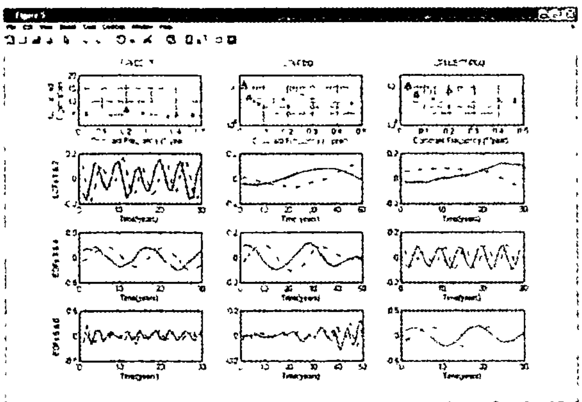
in the module—adapted from a code written by[14]—is divided in four steps: 1) identification of signal structure, 2) signal decomposition, 3) extraction of significant components and 4) reconstruction of significant components and analysis of the residual. Users must choose the window size or embedded dimension to do the analysis and decide which components are significantly different from red noise, which is calculated automatically by generating Monte Carlo simulations of AR(1) processes with the same first and second order statistics of the series. Series must have the same length and be concurrent. The module displays the eigenvalues against the variance explained and their dominant frequencies, pairs of eigenvectors in decreasing order and the observed and reconstructed series using significant components selected by the user (Figures 4a and b)

Wavelets

Wavelets are useful tools in the time-frequency domain for the analysis of non-stationary variances at different time scales. Wavelets decomposition helps identify

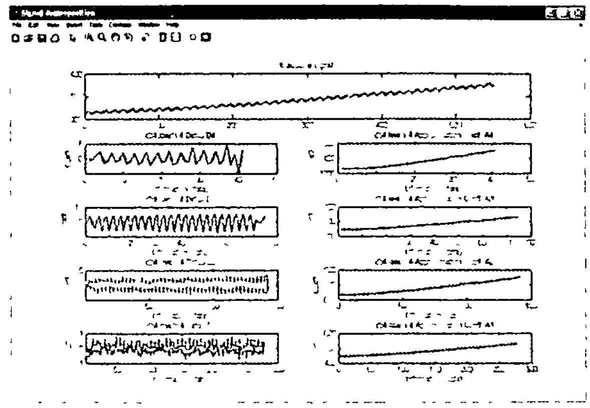


a)

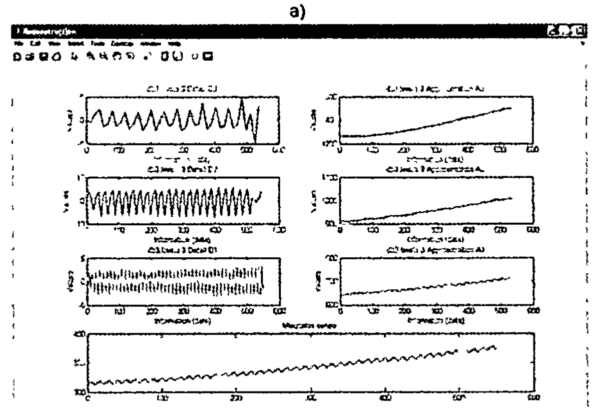


b)

Figure 4. MSSA analysis plots for signal decomposition and reconstruction (three signals analyzed): a) variance explained by eigenvalues, EOF structures and observed and reconstructed series; b) eigenvectors' dominant frequencies and EOF pairs.



a)



b)

Figure 5. Wavelets analysis plots: a) signal decomposition and b) signal reconstruction at different levels.

dominant modes of variability and changes of variability with time[15]. The procedure in the module allows users to: decompose, reconstruct and de-noise a signal in several levels or scales using different wavelet families as filters (i.e., Deubechies, Symlets) (Figure 5). Users define the wavelet filter and the levels to scale or de-noise the signals.

Spatial and temporal analysis

Time series in hydrology are generally associated with processes and variables that are distributed in space. Therefore, the analysis of time series is not restricted to the time and frequency domains but includes the spatial analysis of patterns and features evolving through time. This module aims at introducing techniques that are useful for analyzing spatially-related attributes associated with distributed time series. The module includes principal components, canonical correlation and clustering analyses.

Principal components analysis (PCA)

PCA is a non-parametric technique that transforms a multidimensional set of correlated variables into a set of components that are uncorrelated (orthogonal), with each component explaining a specific amount of variance from the original variables (usually the components are organized in decreasing order of variance explained, being the first components those that explain the most of the variance). The technique is commonly employed to reduce the dimensionality of problems that involve huge datasets (i.e., spatial analysis of distributed variables) by focusing only on those components that explain a significant part of the variance (for a detailed description of PCA see[16]).

The PCA procedure incorporated in the module (Figure 6) allows users to obtain the eigenvalues and their explained variances (in a Pareto diagram, Figure 6a) and the eigenvectors and principal components of a set of observations on several variables (the module centers automatically the variables on their mean values). The module may be employed either to determine principal components of several variables in the same time sequence or to determine principal components of a single variable uniformly distributed in space (each case requires a specific format to introduce the data). If the spatial option is enabled, users can also plot the distribution of mean values and the coefficients of the eigenvectors in the space by specifying the properties of the grid to be plotted (i.e., number of grids in latitude and longitude, grid size or resolution and the coordinates of the bottom left corner). Border lines representing basin limits can also be mapped. Figure 6d shows the spatial plots generated by the module for the mean values and the first three EOFs of the analyzed variable (precipitation in the Colorado Basin).

Canonical correlation analysis (CCA)

CCA is a multivariate statistical technique that correlates multiple dependent variables with multiple independent variables by creating canonical functions from linear composites of the dependent and independent variables (canonical variables) and maximizing the correlation among them (for a detailed description of the method see[17]). The CCA procedure incorporated in the module calculates the eigenvalues and eigenvectors of the cross correlation of two matrices X(n x m) and Y(n x k) which may have different number of sites or variables but the same number of observations. The module normalizes the two sets of variables X and Y introduced by the user and calculates the matrices of canonical correlation coefficients (linear combinations of variables in X and Y) and the matrices of transformed canonical variables (U and V in Figure 7). The module produces a plot of the transformed variables as shown Figure 7.

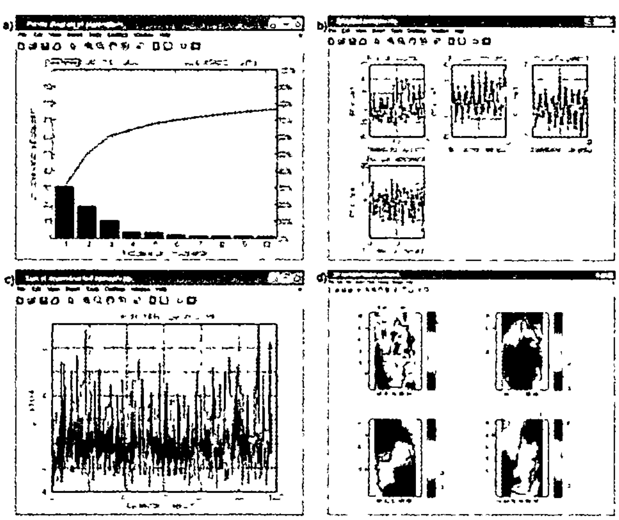


Figure 6. PCA plots: a) eigenvalues (explained variance), b) principal components, c) reconstructed signal and d) spatial distribution of EOF coefficients.

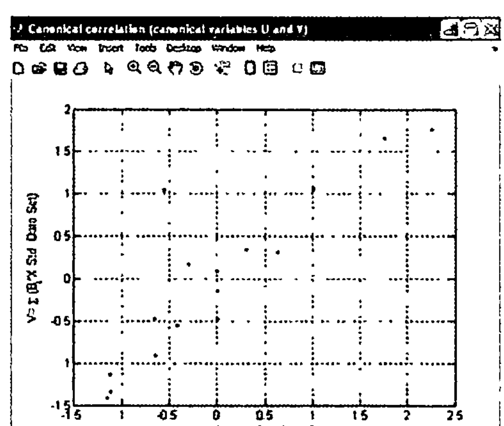


Figure 7. Canonical correlation plot for multiple dependent and independent variables (U and V are the canonical functions derived from the original variables).

Cluster analysis

Cluster analysis encompasses several statistical techniques employed to classify or group data into different sets according to similarity measures (i.e., correlation coefficients).

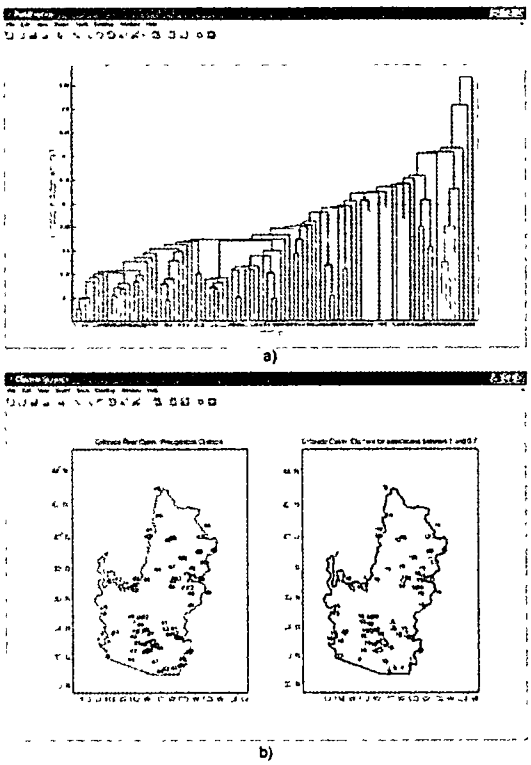


Figure 8. Cluster analysis plots: a) dendrogram and b) spatial distribution of clusters.

Clustering may be particularly useful to visualize spatial features associated with distributed variables[18]. The analysis currently available in the module (Figure 8) uses correlation coefficients as measure of similarity for hierarchical and k-means clustering. It performs the following steps: 1) standardize variables, 2) compute similarity measure (Euclidean distances for correlation coefficients), 3) group data with similar minimum distances (correlations) and 4) plot the clusters in a dendrogram (Figure 8a). The module also allows the mapping of clusters if coordinates are provided by the user (Figure 8b). The user chooses the threshold distance to define the clusters.

State-space models

A state-space model is a mathematical representation of a system defined by inputs, outputs and state variables related by first-order differential equations. Stochastic systems, as those commonly found in hydrology, are characterized by the presence of statistical noise in the system's dynamics and measures. It is, therefore, necessary to filter these noises to estimate the behavior underlying these stochastic systems. The Kalman filter[19] is a popular algorithm to efficiently estimate the most likely state of a stochastic system by recursively filtering the noise from observed signals (usually assumed as Gaussian). The module on state-space models currently implemented includes (Figure 9): a procedure for verifying the stability and convergence of Kalman filter parameter estimates given that

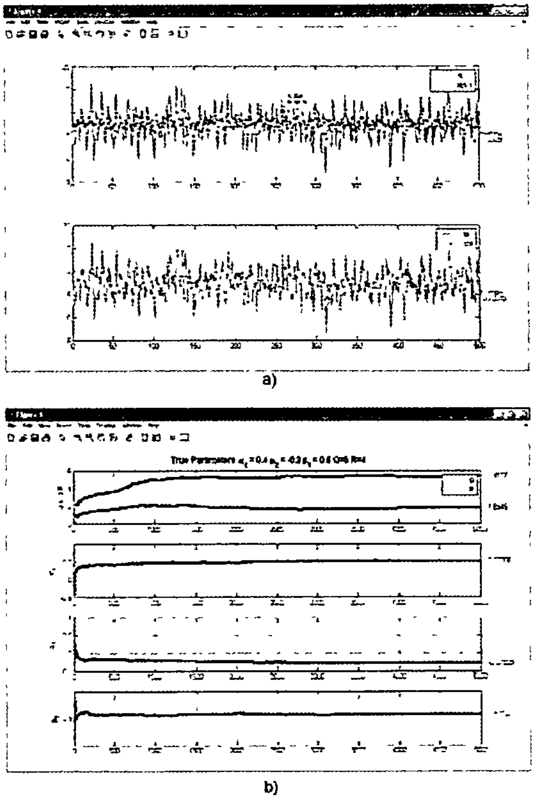


Figure 9. State-space analysis plots for parameter identification and model consistency using the Kalman filter.

both the observed and generated (system) series are known—an ideal situation used to illustrate the application and efficiency of the filter—and a Kalman filter to estimate the state of the system based on observed time series only.

Academic Training

The authors have used UATSA in several graduate courses and workshops on time series analysis at the University of Arizona and at the Universidad de Castilla-La Mancha (Spain) since 2004. The package and sample datasets are distributed among the attendants as an aid to solve homework assignments (participants who are willing to program their own algorithms or want to use other toolboxes are encouraged to do so).

Due to the complementary nature of the software as a teaching aid in structured courses on TSA, UATSA is currently distributed to course students and workshop attendants. In addition, the distribution to a limited group allows the identification of major design and operational issues before any intended release online. A major concern of the authors has been to make the package not only accurate but also user-friendly and appealing, since its main intended purpose is to serve as an academic toolbox (the package has been also employed as a visual aid to illustrate the methods' applications during class time).

Students and workshop attendants (in the order of 10 participants per course) have provided valuable criticism about the software design and have helped to debug the code. There were no evaluation forms for the software at the end of the courses, but rather a continuous feedback from the students as they were working with it along the semester. As a result of this feedback, the authors have incorporated changes in the interfaces and in the management of input and output files (figures and numeric results).

An issue detected by the users of the first version, for instance, was the relative uneasiness to prepare, store and save ASCII data files because many of them were familiar with Excel tables (former versions of the package did not have the option to paste tabulated values directly in the modules). This difficulty was overcome in later versions, mainly with the inclusion of interactive tables. The formatting has also been simplified to define variables in columns and time series in rows for all the modules which facilitates the preparation of datasets by the user. Another issue has been to provide graphical outcomes that are useful for the analysis and require minimum additional editing from the users to be incorporated in their reports.

As mentioned by[1], some versatility is lost when developing and designing user interfaces. In the process of designing the interface, for instance, a critical aspect has been to keep a balance on the number of steps required to do the analysis: too many steps tend to discourage use, but too few reduces the procedure to a black box approach that is not adequate for educational purposes. The authors have opted for minimizing the number of steps that keep the meaning of the procedure clear, including steps for data acquisition, parameter definitions, routine selection and graphical and tabular outputs.

The use of UATSA to illustrate the methods as they are presented in the classroom has served the authors to modify some teaching dynamics by helping students to compare the outcomes from different methods as they dedicate time to understand the meaning of these outcomes and how to integrate them in the problem solving process. As the package evolves to include new methods and algorithms (i.e., Kalman Filtering and the treatment of missing data) it also facilitates the discussion of new topics during class time and workshops.

Developing the application (i.e., writing the software and designing a didactic, error-proof interface) is a time-consuming activity that requires empathy to the users' needs and expectations towards the software, which are neither unique nor convergent. In the authors' experience, this process is most of the time rewarding since it improves the understanding of how to transfer state-of-the-art knowledge to groups using new technologies that goes beyond the conventional instructor-student class interaction.

Acknowledgements

The authors thank the students and participants of the courses and workshops on time series analysis for their valuable comments and significant feedback in the development of this software. Special thanks to Miguel Moreno who, as a post-doctoral attendant to one of the courses, provided the core code for the Kalman filter verification routine. This work was partially supported by SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) at The University of Arizona under the STC Program of the National Science Foundation, Agreement No. EAR-9876800.

References

1. Stephenson, A. and E. Gilleland. "Software for the analysis of extreme events: the current state and future directions," *Extremes*, vol. 8, no. 3, pp. 87-109, 2006

2. Hegger, R., H. Kantz, and T. Schreiber, "Practical implementation of nonlinear time series methods: the TISEAN package," *CHAOS*, vol. 9, 413, 1999

3. Ghil M., R. Allen, M. Dettinger, K Ide, D. Kondrashov, M. Mann, A. Robertson, A. Saunders, Y. Tian, F. Varadi, and P. Yiou, "Advanced spectral methods for climatic time series," *Rev. Geophys*., vol. 40, no. 1, 3.1-3.41, 2002

4. Gilleland, E. and R. Katz, "Tutorial for the Extremes toolkit: weather and climate applications of extreme value statistics." http://www.assessment.ucar.edu/ toolkit, 2005 (accessed April 2008)

5. Shumway, R. and D. Stoffer, *Time series analysis and its applications*, 2nd ed, Springer-Verlag, USA. 2006

6. SpectraWorks "KSpectra toolkit," http://www.spectraworks.com/index.html, 2008 (accessed April 2008)

7. Wessa, P., "Free Statistics Software, Office for Research Development and Education, version 1.1.23-r1," http://www.wessa.net , 2008 (accessed April 2008).

8. MATLAB, *Software help documentation and reference guide*, The Mathworks Inc. USA, 2008

9. Haan, C.T., *Statistical Methods in Hydrology*, 2nd ed, Blackwell Publishing. USA. 2002

10. Bras, R.L., I. Rodriguez-Iturbe, *Random Functions and Hydrology*, Addison Wesley. USA. 1985

11. Vautard R., P. Yiou, M. Ghil, "Singular spectrum analysis: a toolkit for short noisy chaotic signals," *Physica* D 58, 95-126

12. Allen M. R., L. A. Smith, "Monte Carlo SSA: Detecting irregular oscillations in the presence of colored noise," *J. Clim*. 9, 3373-3404, 1996

13. Golyandina, N., V. Nekrutkin, A. Zhigljavsky, *Analysis of Time Series Structure: SSA and Related Techniques*, Chapman & Hall/CRC. USA. 2001

14. Breitenberger, E., "Matlab toolkits for performing Multichannel SSA and Monte Carlo SSA." http://pangea.standford.edu/research/Oceans/GES290/Breitenberger-SSAMatlab, 1997 (accessed October 2005).

15. Torrence, C. and G. P. Compo, "A Practical Guide to Wavelet Analysis," *Bull. Amer. Meteor. Soc*., 79, 61-78, 1998

16. Jolliffe I.T., *Principal Component Analysis*, Springer Series in Statistics, 2nd ed., Springer, New York , 2002

17. Hair, J., R. Anderson, R. Tatham, and W. Black, *Multivariate Data Analysis*, 5th ed, Prentice Hall Inc., 1998

18. Everitt, B., S. Landau and M. Leese, *Cluster analysis*, Arnold, London, 2001

19. Welsh, G. and G. Bishop, "An introduction to the Kalman filter," Department of computer science, University of North Carolina at Chapel Hill, USA. http://www.cs.unc.edu/~welch/kalman/, 2006 (accessed April 2008).

Biographical Information

Julio Cañón is a Professor in the School of Engineering at Universidad de Antioquia (Colombia), a PhD Candidate in Hydrology at the Department of Hydrology and Water Resources of the University of Arizona, a research assistant at the NSF Science and Technology Center SAHRA, and a Fulbright Grantee. His research interest focuses on the multivariate analysis of extreme climatic events and their impacts on water resources systems at different spatial and temporal scales. He is also interested in the development of multimedia aids for integrative generational transfer of knowledge and technology.

Dr. Juan Valdes is a Professor in the Departments of Civil Engineering and of Hydrology and Water Resources at the University of Arizona. He is the Director of the NSF Science and Technology Center SAHRA, member of the Board of Directors for the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) and member of the Scientific Advisory Committee of the Inter American Institute for Global Change Research. Dr. Valdes has held academic and administrative positions at Simon Bolivar University (Caracas, Venezuela), Texas A&M University and the University of Arizona. He is also a fellow of the American Society of Civil Engineers and the American Geophysical Union. His research interests focus on stochastic and deterministic hydrology; flood and drought forecasting; the analysis, synthesis, and sampling of hydrologic processes; mathematical models of natural resources systems; the modeling of space-time precipitation; environmental risk assessment and the stochastic modeling of environmental processes.

Dr. Javier Gonzalez is a Professor in the Department of Civil Engineering at Universidad de Castilla-La Mancha (Spain). He has a Master of Science degree from the University of Arizona (2002) and a PhD from Universidad Politécnica de Valencia (2005). He is member of several International Scientific Committees, including the Surface Hydrology Scientific Committee of the American Geophysical Union. His research interests focus on stochastic and deterministic hydrology; water resources management; paleoclimatic reconstructions and drought characterization; hydrologic and environmental processes modeling; flood and drought risk assessment; and decision support systems development for water management applications.

THE IRON-IRON CARBIDE PHASE DIAGRAM IN MATHCAD

Edwin G. Wiggins
Webb Institute
Glen Cove, NY 11542

INTRODUCTION

A previous article[1] in this journal presented a Mathcad worksheet that does calculations for a simple isomorphous phase diagram. This new article presents a Mathcad worksheet that performs similar calculations for steel in the vicinity of the eutectoid point. It determines the phases present, the relative amount of each phase, and the composition of each phase. Below the eutectoid temperature, the worksheet also calculates the amounts of pearlite and primary phase. Only two user inputs are required – the sample temperature and carbon content. The calculations are valid from 675°C to 900°C and from 0.0218% carbon to 1% carbon. Results are conveniently displayed in a table. The phase diagram, with the state point marked, is also displayed.

Curve Fits in the Phase Diagram

The entire Mathcad worksheet is contained in Figures 1 through 7, but only selected parts of the worksheet are discussed below. Details of the curve fitting are presented in Figure 1, parts (a) and (b). These figures depict the parts of the actual worksheet that do the curve fit calculations.

The A_3 and A_{cm} lines are modeled using Mathcad's cubic spline interpolation features described in the previous article. The boundaries of the all α region above and below the eutectoid temperature are modeled as straight lines. This representation is not as accurate as a cubic spline would be, but it is simpler, and little accuracy is lost, because the composition of the α phase has only a small effect on calculated results.

Cubic spline interpolation in Mathcad is described in detail in the earlier article. A brief discussion of straight line interpolation is provided here. A typical section of the worksheet looks like this:

$$x_l := \begin{pmatrix} 0 \\ 0.0218 \end{pmatrix}\% \qquad y_l := \begin{pmatrix} 900 \\ 727 \end{pmatrix}$$

The line function calculates the intercept and the slope.

Intercept Slope

$$\alpha_l := \mathrm{line}(x_l, y_l) \qquad \alpha_{l_0} = 900\,000 \quad \alpha_{l_1} = -7.936 \times 10^5$$

The function for the α boundary above 727C is simply:

$$a_l(x) := \begin{cases} \alpha_{l_0} + \alpha_{l_1} \cdot x & \text{if } x < 0.0218\% \\ 727 & \text{otherwise} \end{cases}$$

The two values in the array named x_l are the x coordinates (carbon content) of the endpoints of the line, and the two values in the array named y_l are the corresponding y coordinates (temperature). These two arrays are the arguments of the *line* function. Its outputs in array α_l are the slope and the intercept of the line. From these values, the function a(x) creates a straight line that approximates the boundary of the all α region above the eutectoid temperature. The second part of the definition of a(x) draws a horizontal line at the eutectoid temperature. A similar procedure is used to approximate the boundary below the eutectoid temperature.

Brief Discussion of Figures 2 Through 5

Phase compositions are calculated by the equations shown in Figure 2, parts (a) and (b). Tie line analysis is performed by the equations shown in Figure 3, parts (a) and (b). The composition of the phases actually present at the carbon content and temperature chosen by the user are calculated by the equations shown in Figure 4, and the relative amounts of these phases are calculated in Figure 5.

The modeling of lines is limited to the temperature range from 650°C to 900°C. This range encompasses essentially all the interesting activity in steel. Above 900°C there is only austenite, no matter what the carbon content. Below 650°C an unchanging mixture of ferrite and cementite exists no matter what the carbon content. The upper limit on carbon composition in this worksheet is 1.0%. While steel can have more carbon than this, such compositions are not common in plain carbon steel. The lower limit on carbon content is 0.0218%, which is the furthest extent of the all ferrite region.

The worksheet makes all the determinations that can be made by hand. First, it determines which phases are present at a given state point. Possibilities are limited to austenite (γ iron), ferrite (α iron), and cementite (iron carbide). Second, the composition of each phase present is calculated. Third, if the state point is in a two phase region, a tie line calculation is performed to determine the relative amounts of the phases. Fourth, the primary (proeutectoid) phase is determined. This determination is based only on carbon content. If the steel is hypoeutectoid, the worksheet reports ferrite as the primary phase regardless of the temperature. Similarly, if the steel is hypereutectoid, the worksheet always reports iron carbide as the primary phase. If the state point is in the all austenite region, the worksheet is simply reporting the primary phase that will appear when the sample is cooled. Finally, if the state point is below the eutectoid temperature, the worksheet reports the amount of pearlite and the amount of primary phase present.

Mathcad Programming Statements

In many places, the worksheet must make decisions based on carbon content and temperature. This state point determines what phases are present and what equation should be used for tie line calculations. Here is an example:

$$\%Fe3C := \begin{cases} 0 \text{ if } \%C \le 0.77\% \wedge Temp \ge 727 \\ (100\% - \%\gamma) \text{ if } \%C > 0.77\% \wedge Temp \ge 727 \wedge Temp < T_{cm} \\ (100\% - \%\alpha_2) \text{ if } Temp < 727 \\ 0 \text{ otherwise} \end{cases}$$

In the first line, the relative amount of iron carbide is zero if the carbon content is less than 0.77% (the steel is hypoeutectoid), and the temperature is above the eutectoid temperature. In the second line, if the steel is hypereutectoid (carbon content above 0.77%) and the temperature is above the eutectoid temperature, the relative amount of iron carbide is 100% minus the percentage of austenite, which has already been calculated. If the temperature is below the eutectoid temperature, the relative amount of iron carbide is calculated in the third line as 100% minus the relative amount of ferrite, which has already been calculated. Finally, if none of the conditions in the first three lines is met, the relative amount of iron carbide is set to zero. There are many other structures like this in the worksheet, and the general idea is the same.

Use of the Worksheet

The user need not be concerned with Figures 1 through 5. All he or she needs to do is enter the carbon content and temperature at the top of Figure 6. The table of output information appears in a table directly below the inputs. Finally, the phase diagram itself, with state point displayed as a red diamond, is displayed in Figure 7.

Output values are collected in a table shown just below the input values in Figure 6. In this example, at 675°C and a carbon content of 0.95%, the table appears as follows:

""	"Phase 1"	"Phase 2"
"Name"	"ferrite"	"carbide"
"Composition (%C)"	0	6.67
"Relative Amount (%)"	85.757	14.243
"Primary Phase"	"carbide"	""
"Amt Pri Phase (%)"	3.051	""
"Amount Pearlite (%)"	96.949	""

As expected for hypereutectoid steel below the eutectoid temperature, the phases present are ferrite and iron carbide. The primary phase is iron carbide, which makes up 3% of the sample. The remainder of the sample is pearlite. In Mathcad, all numerical values in a table must show the same number of decimal places. In order to display three decimal places for the carbon content of ferrite, the table must be formatted to display three decimal places for all results. As a consequence the number of decimal places shown for the relative amounts of phases is often excessive. Figure 7 shows the phase diagram that appears at the end of the worksheet. Similar tables and phase diagrams can be generated for any carbon content between 0.0218% and 1% and temperatures between 650°C and 900°C. The worksheet has been tested in all regions of the diagram that fall within these limits, and the results are accurate.

Note that if the temperature is exactly 727°C, the phases present, their compositions, and their relative amounts are indeterminate. To avoid problems with the worksheet, it must be set to give arbitrarily chosen output at this temperature, but that output is not meaningful.

Summary

Like the isomorphous phase diagram worksheet described in the earlier article, this worksheet is intended as a tool for the instructor in a basic materials science course. Display of the state point is easily suppressed, and the printed phase diagram can be given to students as part of a test or homework assignment. The instructor can quickly and easily prepare the solution key. Only the last two pages of the worksheet need be printed. The last page contains the phase diagram, and the next to last page contains the input values and the output table.

References

1. Wiggins, Edwin G., "Isomorphous Phase Diagrams in Mathcad, A Powerful Tool for Instructors" Computers in Education Journal, Vol. XVII, no. 3, p.106.

Biographical Information

Edwin G. Wiggins holds BS, MS, and Ph.D. degrees in chemical, nuclear, and mechanical engineering respectively from Purdue University. He is the Mandell and Lester Rosenblatt Professor of Marine Engineering at Webb Institute in Glen Cove, NY. Ed is a past chairman of the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers (SNAME) and a past regional vice president of SNAME. As a representative of SNAME, Ed Wiggins served on the Technology Accreditation Commission, the Engineering Accreditation Commission, and the Board of Directors of the Accreditation Board for Engineering and Technology (ABET). A Centennial Medallion and a Distinguished Service Award recognize his service to SNAME.

The worksheet models the iron-iron carbide phase diagram in the vicinity of the eutectoid point (650C to 900C and 0.0218%C to 1%C.

Above 727C there are 3 lines to be represented: the α boundary, the A_3 and the A_{cm}. For the α boundary, a straight line is sufficiently accurate. First equations are developed for these lines. The line for the α boundary is developed as follows:

Below 727C there is a different α boundary at the left and 6.67%C at the right.

So, the α boundary above 727C is represented as a straight line. Here are the endpoints.

$$x_1 := \begin{pmatrix} 0 \\ 0.0218 \end{pmatrix}\% \qquad y_1 := \begin{pmatrix} 912 \\ 727 \end{pmatrix}$$

The line function calculates the intercept and the slope.

	Intercept	Slope
$\alpha_1 := \mathrm{line}(x_1, y_1)$	$\alpha_{1_0} = 912.000$	$\alpha_{1_1} = -8.486 \times 10^{5}$

The function for the α boundary above 727C is simply:

$$a_1(x) := \left| \begin{array}{l} \alpha_{1_0} + \alpha_{1_1} \cdot x \ \text{ if } x < 0.0218\% \\ 727 \ \text{ otherwise} \end{array} \right.$$

For the A_3 line, cubic spline interpolation is used. Here are the data points.

$$x_2 := \begin{pmatrix} 0 \\ 0.2 \\ 0.4 \\ 0.6 \\ 0.77 \end{pmatrix}\% \qquad y_2 := \begin{pmatrix} 912 \\ 828 \\ 781 \\ 750 \\ 727 \end{pmatrix}$$

$$vs := \mathrm{cspline}(x_2, y_2)$$

Here is the continuous function for the A_3 line.

$$A_3(x) := \mathrm{interp}(vs, x_2, y_2, x)$$

Figure 1 (a)

A_3 and α Boundary Curve Fit Above 727°C

For the Acm line, cubic spline interpolation is used again. Here are the data point

$$x_4 := \begin{pmatrix} 0.77 \\ 0.9 \\ 1 \end{pmatrix}\% \qquad y_4 := \begin{pmatrix} 727 \\ 782 \\ 820 \end{pmatrix}$$

$$vt := \text{cspline}(x_4, y_4)$$

Here is the continuous function for the A_{cm} line.

$$A_{cm}(x) := \text{interp}(vt, x_4, y_4, x)$$

The A_3 and the A_{cm} lines are combined into a single function below.

$$A(x) := \begin{vmatrix} A_3(x) & \text{if } x < 0.77\% \\ A_{cm}(x) & \text{if } x \geq 0.77\% \end{vmatrix}$$

For the α boundary below 727C, another straight line is used.

$$x_3 := \begin{pmatrix} 0 \\ 0.0218 \end{pmatrix}\% \qquad y_3 := \begin{pmatrix} 675 \\ 727 \end{pmatrix}$$

The line function calculates the intercept and slope.

Intercept Slope

$$\alpha_2 := \text{line}(x_3, y_3) \qquad {\alpha_2}_0 = 675.000 \qquad {\alpha_2}_1 = 2.385 \times 10^5$$

The function for the α boundary below 727C is simply:

$$a_2(x) := \begin{vmatrix} {\alpha_2}_0 + {\alpha_2}_1 \cdot x & \text{if } x < 0.0218\% \\ 727 & \text{otherwise} \end{vmatrix}$$

Figure 1 (b)
Acm and α Boundarv Curve Fit Below 727°C

Composition of Fe_3C

$\text{Carbide} := 6.67\%$

A range variable for the x coordinate in the phase diagram below.

$x := 0\%, 0.01\%..1\%$

Redefine α_1 and α_2 for convenience below.

$\alpha_a(z) := \alpha_{1_0} + \alpha_{1_1} \cdot z$

$\alpha_b(z) := \alpha_{2_0} + \alpha_{2_1} \cdot z$

In the α and γ region:

$T_3 := A_3(\%C)$ $T_3 = 699$ The temperature on the A3 line at the system composition.

The phase compositions are calculated by a solve block. Here are the guess values.

$\alpha := 0.02\%$ $\gamma_1 := 0.4\%$ $\beta := 0.02\%$

Given

$\alpha_a(\alpha) = \text{Temp}$

$\alpha_b(\beta) = \text{Temp}$

$\begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} := \text{Find}(\alpha, \beta)$ $\alpha_1 = 0.028 \cdot \%$ $\alpha_2 = 0.0000 \cdot \%$

For any given system temperature only one of the αs is valid. The ferrite variable belov contains the valid one.

$\text{ferrite} := \begin{vmatrix} \alpha_1 & \text{if Temp} \geq 727 \\ \alpha_2 & \text{if Temp} < 727 \end{vmatrix}$

$\text{ferrite} = 0.0000\ \%$ The ferrite composition

Figure 2 (a)
Calculation of Femte and Cementite Phase Compositions

The second part of the A3 function below is phony but necessary for some of the calculations below. Continuous values above %C of 0.0218% are required.

$$A_3(x) := \begin{cases} A_3(x) & \text{if } x \le 0.77\% \\ (727 - 100x) & \text{otherwise} \end{cases}$$

Given

$$A_3(\gamma_1) = \text{Temp}$$

$\gamma_1 := \text{Find}(\gamma_1)$ $\gamma_1 = 52.000 \cdot \%$ γ composition for hypoeutectoid steel at Temp

In the γ and iron carbide region:

$T_{cm} := A_{cm}(\%C)$ $T_{cm} = 801$ The A_{cm} temperature at the sample composition

$\gamma_2 := 0.9\%$ a guess value

Given

$$A_{cm}(\gamma_2) = \text{Temp}$$

$\gamma_2 := \text{Find}(\gamma_2)$ $\gamma_2 = 0.67 \cdot \%$ γ composition for hypereutectoid steel at Temp

There are two values of γ composition above, but only one is valid. The statements below select the proper one.

$$\gamma := \begin{cases} \gamma_1 & \text{if Temp} < T_3 \wedge \text{Temp} > 727 \wedge \%C < \gamma_1 \\ \gamma_2 & \text{if Temp} < T_{cm} \wedge \text{Temp} > 727 \wedge \%C > \gamma_2 \\ \%C & \text{otherwise} \end{cases}$$

$\boxed{\gamma = 0.95 \cdot \%}$

Figure 2 (b)
Calculation of Austenite Phase Composition

Tie line calculation above 727C

$$\%\gamma_1 := \frac{\%C - \alpha}{\gamma_1 - \alpha} \qquad \boxed{\%\gamma_1 = 1.8\cdot\%}$$

$$\%\alpha_1 := 100\% - \%\gamma_1 \qquad \%\alpha_1 = 98.2\cdot\%$$

$$\%\gamma_2 := \frac{6.67\% - \%C}{6.67\% - \gamma_2} \qquad \boxed{\%\gamma_2 = 95.3\cdot\%}$$

$\%Fe3C := 100\% - \%\gamma_2 \quad \%Fe3C = 4.651\cdot\%$ Valid only for hypereutectoid

There are 2 values of relative amount of γ above, but only one is valid. The statement below select the proper one.

$$\%\gamma := \begin{cases} \%\gamma_1 \text{ if } Temp < T_3 \wedge Temp > 727 \wedge \%C < \gamma_1 \\ \%\gamma_2 \text{ if } Temp < T_{cm} \wedge Temp > 727 \wedge \%C > \gamma_2 \\ 0 \text{ if } Temp < 727 \\ 100\% \text{ otherwise} \end{cases}$$

$$\boxed{\%\gamma = 0.0\cdot\%}$$

Tie line calculation below 727C

Given

$$\alpha_b(\alpha) = Temp$$

$$\alpha_2 := Find(\alpha)$$

$$\alpha_2 = 0.0000\cdot\%$$

$$\%\alpha_2 := \frac{Carbide - \%C}{Carbide - \alpha_2}$$

$\%\alpha_2 = 85.757\cdot\%$ The relative amount of α IF the steel is below 727C

Figure 3 (a)
Tie Line Calculations Part 1

The statements below calculate the relative amount of Fe_3C for various cases

$$\%Fe3C := \begin{cases} 0 \text{ if } \%C \le 0.77\% \wedge Temp \ge 727 \\ (100\% - \%\gamma) \text{ if } \%C > 0.77\% \wedge Temp \ge 727 \wedge Temp < T_{cm} \\ (100\% - \%\alpha_2) \text{ if } Temp < 727 \\ 0 \text{ otherwise} \end{cases}$$

$\%Fe3C = 14.243 \cdot \%$

$$\%Pearlite := \begin{cases} \dfrac{\%C - \alpha_2}{0.77\% - \alpha_2} \text{ if } \%C \le 0.77\% \wedge \%C \ge \alpha_2 \wedge Temp < 727 \\ \dfrac{Carbide - \%C}{Carbide - 0.77\%} \text{ if } \%C > 0.77\% \wedge Temp < 727 \\ 0 \text{ otherwise} \end{cases}$$

$\%Pearlite = 96.9 \cdot \%$

The statement below determines what the primary phase is

$$PriPhase := \begin{cases} \text{"ferrite" if } \%C < 0.77\% \\ \text{"carbide" if } \%C > 0.77\% \\ \text{"NA" otherwise} \end{cases}$$

The statement below calculates the amount of primary phase for various case

$$AmtPriPhase := \begin{cases} (100\% - \%Pearlite) \text{ if } Temp < 727 \\ \%\alpha_1 \text{ if } Temp \ge 727 \wedge \%C \le 0.77\% \\ 100\% - \%\gamma \text{ if } Temp \ge 727 \wedge \%C > 0.77\% \\ 0 \text{ if } \%\gamma = 100\% \end{cases}$$

PriPhase = "carbide"

$AmtPriPhase = 3.1 \cdot \%$

Figure 3 (b)
Tie Line Calculations Part 2

The statement below determines the identity of one of the phases present.

$$\text{Phase}_1 := \begin{array}{|l} \text{"ferrite" if } Temp \le T_3 \wedge \%C \le 0.77\% \wedge Temp > 727 \\ \text{"carbide" if } Temp \le T_{cm} \wedge \%C \ge 0.77\% \wedge Temp > 727 \\ \text{"ferrite" if } Temp < 727 \\ \text{"austenite" otherwise} \end{array}$$

$\text{Phase}_1 = \text{"ferrite"}$

The statement below determines the identity of the other phase present. If only one phase i present, it must be γ. Both Phase_1 and Phase_2 will evaluate to "austenite."

$$\text{Phase}_2 := \begin{array}{|l} \text{"austenite" if } Temp \ge 727 \\ \text{"carbide" otherwise} \end{array}$$

$\text{Phase}_2 = \text{"carbide"}$

The statement below determines the composition of Phase_1

$$\text{CompPhase1} := \begin{array}{|l} \text{ferrite if } Temp \le T_3 \wedge \%C \le 0.77\% \wedge Temp > 727 \\ 6.67\% \text{ if } Temp \le T_{cm} \wedge \%C \ge 0.77\% \wedge Temp > 727 \\ \text{ferrite if } Temp < 727 \\ \gamma \text{ otherwise} \end{array}$$

$\text{CompPhase1} = 0.000\ \%$

The statement below determines the composition of Phase_2

$$\text{CompPhase2} := \begin{array}{|l} \gamma \text{ if } Temp \ge 727 \\ \text{Carbide otherwise} \end{array}$$

$\text{CompPhase2} = 6.670 \cdot \%$

Figure 4
Determine of Compositions of Phases Actually Present

The statement below determines the relative amount of $Phase_1$

$$AmtPhase1 := \begin{cases} \%\alpha_1 & \text{if } Temp \le T_3 \wedge \%C \le 0.77\% \wedge Temp > 727 \\ \%Fe3C & \text{if } Temp \le T_{cm} \wedge \%C \ge 0.77\% \wedge Temp > 727 \\ \%\alpha_2 & \text{if } Te\ \ p < 727 \\ \%\gamma & \text{otherwise} \end{cases}$$

The statement below determines the relative amount of $Phase_2$

$$AmtPhase2 := \begin{cases} \%\gamma & \text{if } Temp \ge 727 \\ \%Fe3C & \text{otherwise} \end{cases}$$

The matrix below assembles the values for the table that follows.

$$Phases := \begin{pmatrix} \text{""} & \text{"Phase 1"} & \text{"Phase 2"} \\ \text{"Name"} & Phase_1 & Phase_2 \\ \text{"Composition (\%C)"} & CompPhase1 \cdot 100 & CompPhase2 \cdot 100 \\ \text{"Relative Amount (\%)"} & AmtPhase1 \cdot 100 & AmtPhase2 \cdot 100 \\ \text{"Primary Phase"} & PriPhase & \text{""} \\ \text{"Amt Pri Phase (\%)"} & AmtPriPhase \cdot 100 & \text{""} \\ \text{"Amount Pearlite (\%)"} & \%Pearlite \cdot 100 & \text{""} \end{pmatrix}$$

Figure 5
Determination of Amounts of Phases Actually Present

At the following state point (enter values below)

$\%C \equiv 0.95\%$ $\qquad$ $Temp \equiv 675$

Values are as follows

Phases =

""	"Phase 1"	"Phase 2"
"Name"	"ferrite"	"carbide"
"Composition (%C)"	0	6.67
"Relative Amount (%)"	85.757	14.243
"Primary Phase"	"carbide"	""
"Amt Pri Phase (%)"	3.051	""
"Amount Pearlite (%)"	96.949	""

Figure 6
User Inputs and Mathcad Outputs

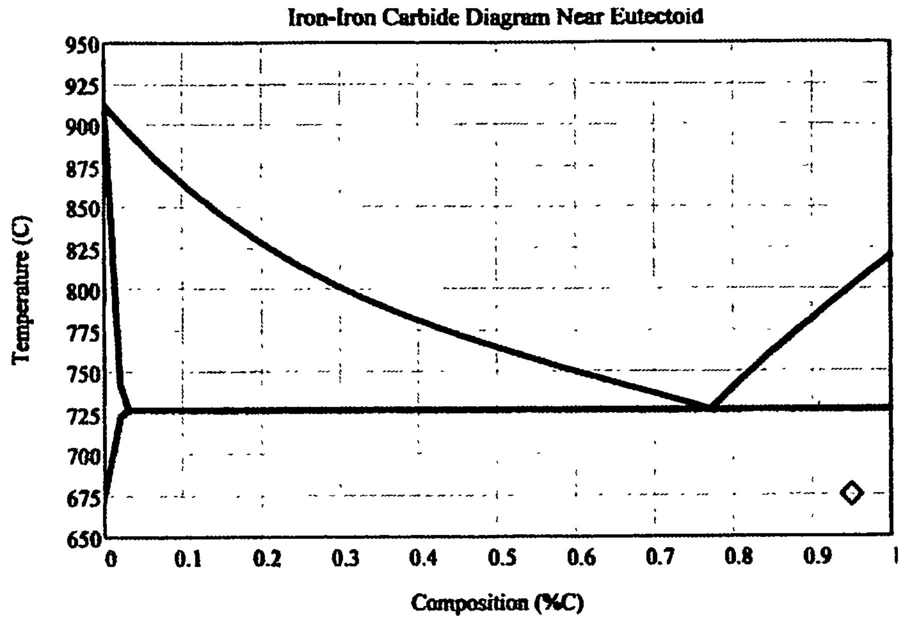
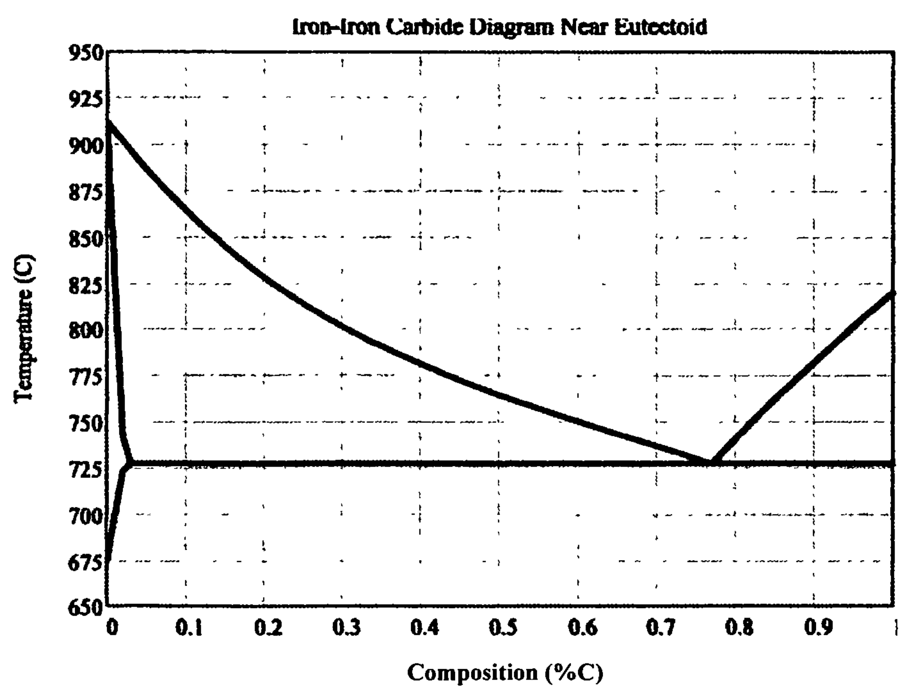


Figure 7
Phase Diagram With State Point



VISUALIZATION AIDS FOR POWER SYSTEM COMPUTATIONS

Peter Idowu, Mohamed Omer
Penn State University – Harrisburg,
Middletown, PA 17057

Abstract

Many electrical engineering programs are caught up in the struggle over what to include as core requirements of the program especially at the senior level. Often, specialty areas compete to have their favorite courses designated as a core requirement. The status, long enjoyed by power engineering courses is however currently being threatened, as more programs no longer see the need to require a power system or energy conversion course. In order to include what the student needs to know about energy systems in the undergraduate curriculum, electric power engineering educators must creatively consolidate course topics that traditionally span two or more courses into one. Traditional pedagogical approach becomes grossly inadequate for addressing the challenges. This paper presents three interactive MATLAB® simulation programs for aiding students in learning three core power system analysis algorithms – power flow, economic dispatch and unit commitment.

Index Terms—Education, Power flow, Economic dispatch, Unit Commitment, Visualization.

Introduction

The challenges of presenting electric power engineering concepts to students in such a way that would bring about clarity, while at the same time keeping students' interest sustained have been highlighted in many research works. While this challenge is not unique to the power engineering field it has however engaged the attention of educators for a while because of concerns that it may be playing a part in their perceived declining interests in the power area over the last decade [1-5]. Power engineering educators have offered an impressive array of options for addressing the needs. There is consensus on the view that a wider application of digital technology in learning is the key to reversing the undesirable trend. The case has been made for some form of computer-assisted learning environment that is interactive, either as a stand-alone or online web-based collaborative tool [6-11]. These avenues, it is argued, would demonstrate innovative trends in the use of computers, and exploit the capabilities of the Internet for distance education, while providing access to physical laboratory equipment through some form of remote access.

Kezunovic et al [6] related findings of an NSF (National Science Foundation) funded research project aimed at developing new teaching methods for power engineering courses. It noted that computer modeling and simulation were viewed positively and judged to offer more powerful insight into power engineering topics. A variety of tools ranging from custom applications to commercial modeling simulation environment offer features for helping learners make associations between cause (inputs) and effects (outputs), as well as information visualization that are helpful for clarifying concepts. The trend in general-purpose toolboxes and commercial simulation systems is towards user interfaces that facilitate ease of use and quicker development of system models. However, the typical commercial power system simulation program is both comprehensive and complex. It would present a formidable challenge for the average student to learn and demonstrate some measure of competence within the limited time in a three-credit first course in power system. Since undergraduate curriculum needs are not the fundamental criteria in the development of commercial power system packages it should not be expected that they would address conceptual difficulties students will experience in course of the delivery of a topic. Moreover, the same conceptual difficulties are not necessarily present every time the same course is offered. Difficulty experienced may be due to inadequate preparation of students, or to the style of the course instructor. This would therefore suggest that some form of custom-developed tool is essential, and the better option to adequately address learning needs in the classroom as perceived by the instructor.

This paper presents three custom-developed simulation programs to aid the visual learning process for undergraduates taking an introductory course in power or energy systems. The package developed using the graphical user interface (GUI) toolbox in MATLAB®7.0 [12] brings the graphical interface capabilities into use to enable students to visualize the effects of parameter changes in the configuration of the power system under study. The learning tool enables users to see the flow of information and the intermediate steps or results in commonly used power system algorithms. Commercial power system programs do not routinely offer this flexibility or insight.

The simulation packages were geared towards illustrating three computation problems in power system analysis: power flow (PF), economic dispatch (ED), and unit commitment (UC). These are individually addressed in the sections of this paper.

Power Flow

Power flow studies are of vital importance in the design, planning, and operation of power systems. This underlies the basis of its inclusion in the curriculum. Power flow analysis is fundamentally a three-phase AC circuit problem that should not present a mystery to the typical electrical engineering undergraduate. However, it could quickly become a source of great confusion within the context of a first course in power systems because new elements (transmission lines, synchronous generator and transformers) introduced into the circuit model, brings along characteristics that elevate complexity of network modeling equations. The per-unit method is used for normalizing data, and to remove the partitioning effect that transformers bring into the problem, while the bus admittance technique is used for organizing network data. A numerical solution algorithm, such as Newton-Raphson is commonly used for iteratively obtaining bus voltages, currents and power flows. Derivation of the power flow equations, generalization for the n-bus system and reorganization of equations into compact vector/matrix form should precede discussion of the Newton-Raphson algorithm (Appendix). This array of new concepts could unduly impose on the limited time to cover other important concepts. It therefore behooves the course instructor to seek options for quick clarification of the concepts and processes.

Power systems simulation programs have been around for many years. Some of the prominent ones include Positive Sequence Load Flow (PSLF) [13], PowerGraph [14] and PowerWorld [15]. Although targeted towards educational uses PowerGraph does not offer the user insights on computations performed in the background. PowerWorld on the other hand is highly interactive and offer some animation and attractive visual metaphors to facilitate learning. It is integrated into some power system analysis textbooks; however it is primarily commercial software which was not designed to target specific academic learning objectives.

In this section two visual aids developed for clarifying the power flow solution process is presented. The first attempts to explain the process or method for solving the power flow problem without getting into all the fine details of the solution. A flowchart representation of the problem, via Newton-Raphson method, is displayed. The user could review the solution of the problem step by step, as shown in Fig. 1, thereby obtaining comprehensive understanding of the problem and method used in its solution.

The user is given access to a number of parameters of the power system through the visual interface of Fig. 1. For instance, the designated system slack bus may be changed through a pull-down menu or a transmission line eliminated on the "Modify System" group. Transmission line impedance and susceptance may be modified as desired through the menu on the "Modify Line Data" section, where Line 1 2, for instance denotes the connection between bus 1 and bus 2.

Students are exposed to the mathematical equations being used to represent the system, the type of parameters being calculated at each step, how and which of the parameters change during each numerical iteration. The active flowchart updates parameters in real time. In other words, the package exposes the student to the process taking place behind the typical graphical representation of the system in commercial software packages.

The second approach uses a graphical representation of the system in the form of the power grid. To decrease the abstraction of the system representation, the conventional one-line diagram is not used in this approach. This is because the average student in power engineering courses, have difficulty comprehending and relating the one-line diagram to the physical existence of the system. Therefore, the system is represented as a power grid in which lines are drawn in a shape similar to real transmission lines as shown in Fig. 2.

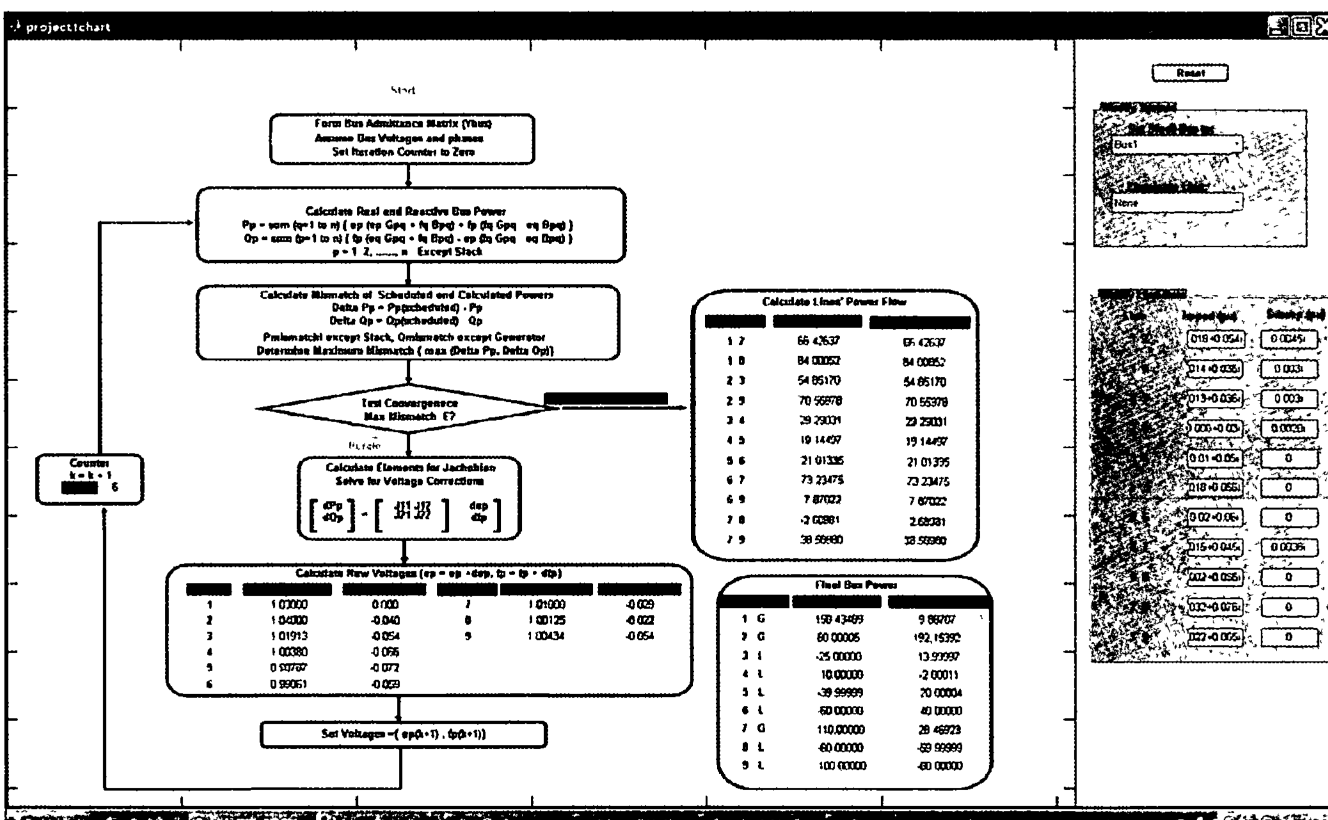


Fig. 1. Power Flow Visualization (Flow chart).

Further, pictures of industrial or residential areas depict loads, while generating units are displayed as real pictures of power plants. This representation enables students to relate the problem to the physical power system and its parameters. The package enables users to obtain a final, complete solution of the problem where the quantities are displayed over the grid and directions of the line-flows are shown with arrows. The user may elect to solve the problem iteratively where the solutions of each of the iterations are displayed over the grid.

One of the main concepts illustrated by the package is the classification of buses. In general, there are three types of buses: load bus, generator, and swing or slack bus. At a load bus, the real and reactive powers are held fixed during power flow studies. For a generator bus, the controlled variables are the bus voltage magnitude and the real power output, while at the slack bus voltage magnitude and angle are pre-specified. This bus classification is illustrated in the iterative method; the user would notice the variables that change at each iteration and the ones that remain fixed. Further, the package menu enables the user to change line impedance values and bus type designation, or even disconnect transmission lines from network. This offers the student a learning environment for in-depth understanding of the role and effect of these parameters on the power flow study and operation of the system.

The power flow visualization tool is designed for a 9-bus power system but may be modified or adapted for a smaller or larger system. This requires access to a MATLAB® programming

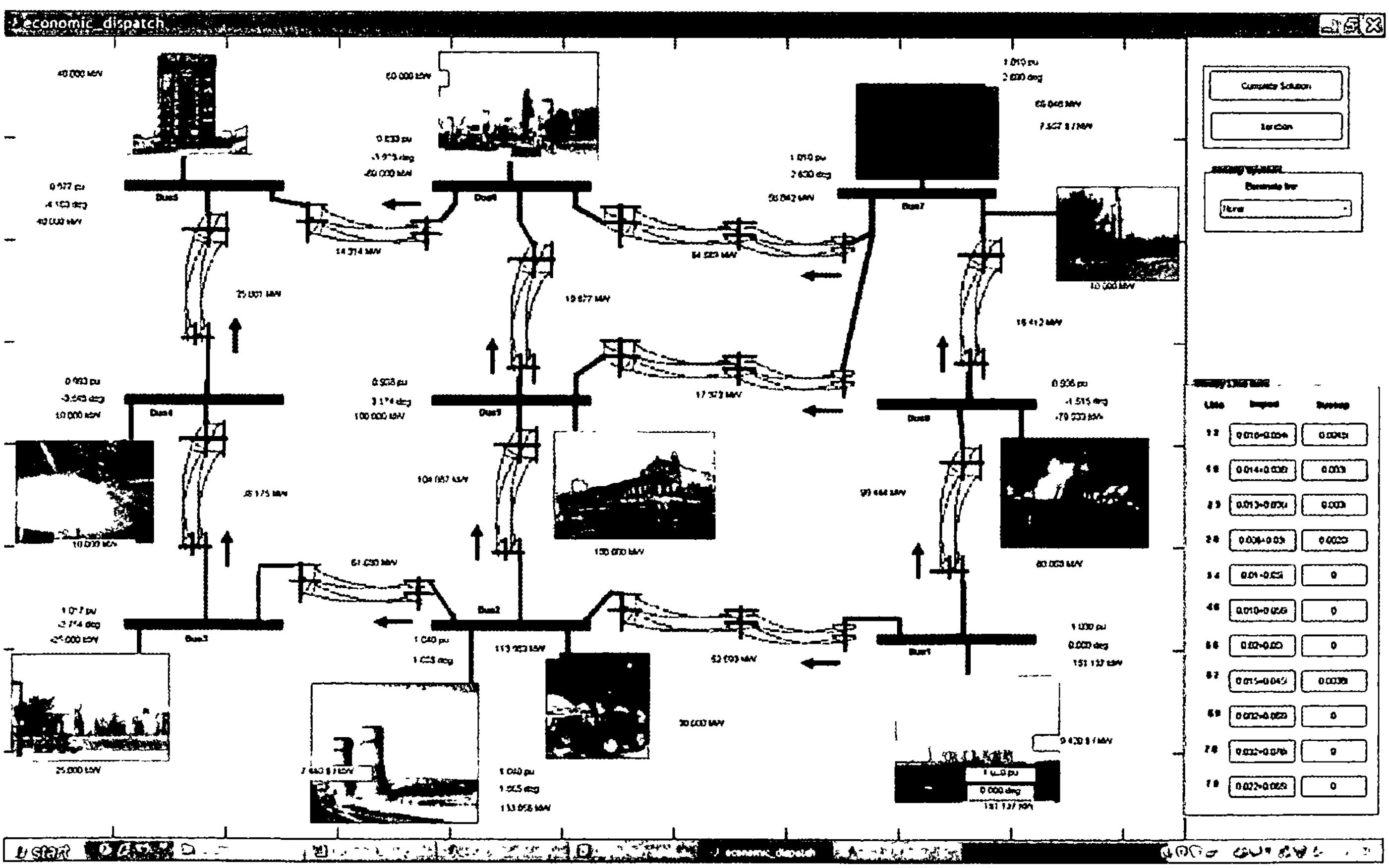


Fig. 2. Power Flow Visualization (Power grid).

environment. The source code for the visualization tool is free and accessible from the download website - <http://peteridowu.googlepages.com/>.

Economic Dispatch

The modern power system such as exists in North America is an interconnection of several generator groups, thousands of miles of transmission lines and blocks of demand loads. The infrastructure provides the critical medium for assuring some measure of electric system reliability, and an avenue for economic allocation of generator outputs to ensure system-wide loss minimization. In its simplest form the economic dispatch (ED) problem attempts to minimize power production costs and line losses, within constraints of physical limits or requirement of power system elements.

The information obtained from the ED study includes the power output of each generator unit, voltage magnitude, phase angle, power flows and losses on lines. Further, the ED study would inform the operator of the actual and incremental cost of delivering power to satisfy a certain demand level in the system. This topic should have a place within the first course in power system, given the fact that it highlights an area of application where power production costs and energy loss reduction on a large scale have long been the tradition.

The problem is traditionally formulated as a constrained optimization problem, and solved using the Lagrange multiplier method [16] (Appendix). The resulting nonlinear problem is solved iteratively, with required power flow analysis within the iteration of the ED solution algorithm. The challenge is centered on how to present this concept concisely within the first course in power system. In order to demonstrate some grasp of the concept the student would need an understanding of the Lagrange multiplier method, an iterative solution technique for non-linear equations, and power flow analysis.

The approach to the ED problem visualization is similar to that proposed in the power flow case. First, a process description is used in a form of flowchart (Fig. 3) to illustrate and provide an understanding of the mathematical representation and the iterative Lagrange multiplier method. Working with this form of the ED problem representation, the user is guided through the steps involved in solving the ED problem. The role of each equation and the effect of the parameters on the optimal solution are easily observed. This provides an in depth understanding of the process taking place in the background of the typical graphical representation in commercial packages. In addition to the flowchart view, Fig. 3 shows critical system parameters that may be changed. A line could be eliminated from the system by making a selection from the "Modify System" pull-down list, changes are made to generator cost functions from the "Modify Cost Function Coefficients" group and transmission line data from the "Modify Line Parameters" group.

A graphical representation of the ED problem, similar to that described for the power flow problem shown in Fig. 2 is provided to the user. The user may view a complete solution of the problem or iterate through each step. Further, user could change system parameters, such as line impedances and generator cost function parameters, or view the effect of transmission line removal on the performance of the power system. In addition, the user can review how the incremental cost of each generator changes iteratively.

Unit Commitment

The unit commitment (UC) problem is a formulation of the process for determining start-up and shutdown schedules for generating units in order to satisfy load forecast requirements at the minimum cost. It is generally unfamiliar to typical electrical engineering undergraduates as the subject falls outside the scope of

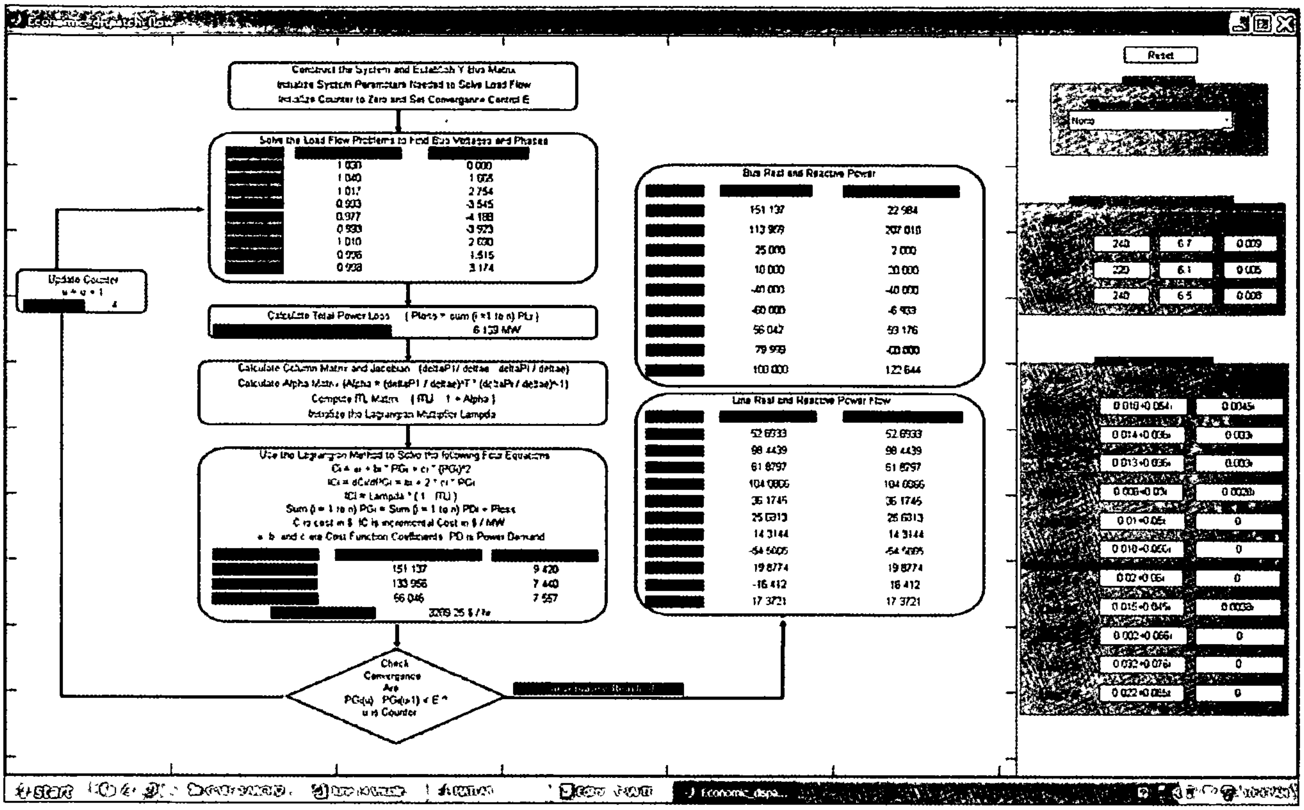


Fig. 3. Economic Dispatch Visualization (Flow chart).

introductory level power engineering course. The subject however touches on physical or practical limitations of energy conversion devices, the knowledge of which could yield further enlightenment and broaden the perspective of the student. The UC problem solution factors in generator minimum up time and downtime before de-committing or re-committing respectively, must-run units, spinning reserve and crew constraints, among others. The dynamic programming algorithm [16, 17] performs a "forward pass" to determine minimum "production cost" of possible combinations of generators over each interval of the forecasted demand. This is the sum of economic dispatch (ED) costs of generators in each feasible set. The forward pass is followed by "backward" sweeps to recursively determine the least total cumulative cost to arrive at the final interval by summing production and transition costs between intervals.

For the unit commitment visualization tool only a subset of the parameter are considered, such as the cost associated with starting and shutting down of units, and the maximum and minimum power output capability of the generating units. Further, only a lossless case of the power system is considered. A sample system comprised of four generating units, with some "must-run" constraints is used to demonstrate the UC problem. In the graphical representation of the problem, a grid is constructed for six stages of the load cycles, in which each node depicts the availability of a particular generator group and the cost associated with it, as shown in Fig. 4. The visual tool interface provides access to generator cost function coefficients, minimum and maximum generator power settings, system loading during each stage of load cycles, and interactive buttons to initiate dynamic programming.

The interactive solution method consists of two main sweeps. The first is a backward sweep in which the solution determines the availability of the generator group and its operation cost in each of the six stages of the day. A forward sweep follows the previous one to determine sequence of generator groups that would result in the minimum and efficient solution. The user is able to follow the step-by-step process of dynamic programming and how decisions are made at each stage. Further, the package enables its user to change certain system parameters, such as the total load levels during the six cycles of the day, the maximum and minimum real power output of generating units, and the cost function parameters of the generator units. Therefore, the user would gain understanding of the role and effect of these parameters on system operation, cost and performance.

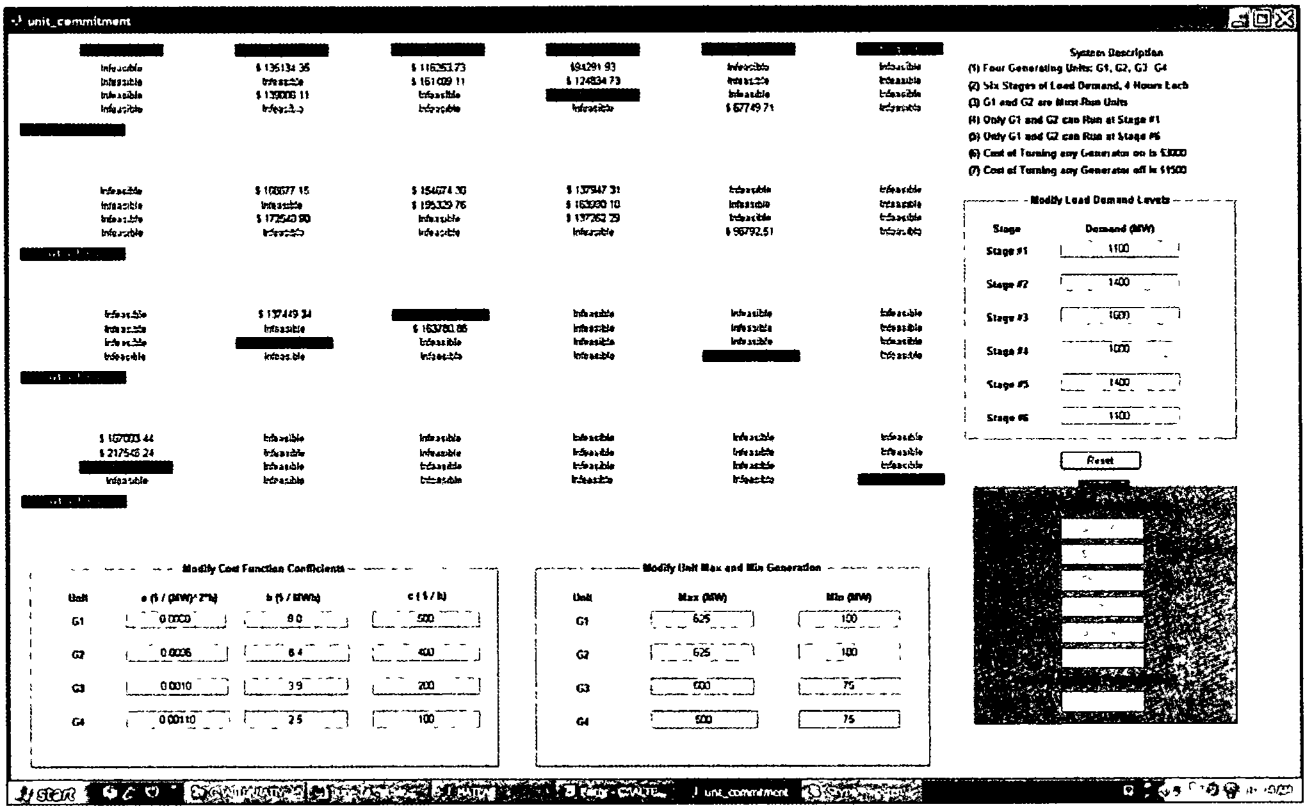


Fig. 4. Unit Commitment Visualization.

Conclusions and Future Improvement

This paper presents three MATLAB® based simulation programs to aid the visual learning process for undergraduates taking an introductory course in power systems analysis and computations. The tool enables students to visualize the effects of changes in the configuration of the power system under study, and to observe the flow of information and the intermediate steps. The simulation tool focuses on three important power system analysis problems: power flow, economic dispatch, and unit commitment. Although some commercial power system programs offer free educational versions with limited features, they do not routinely offer the insight on the computation process. The flexibility does not exist for users to modify the program in order to address learning needs in the undergraduate classroom. Since the proposed simulation tools is implemented with a readily available development environment: MATLAB®, it improves accessibility to students. Also, it offers an avenue for course instructors to improve the learning environment by targeting simulation models to address learning needs. The wider use of user-developed simulation tools will ensure that important concepts and processes that require clarifications will receive due attention in course of the ever-shortening length of time to accomplish it. The three simulation programs are available for download from: <http://peteridowu.googlepages.com/>

Appendix

Newton-Raphson power flow problem [16]:

$$I = Y_{Bus} V \qquad (1)$$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \qquad (2)$$

V and I are bus voltages and currents respectively. δ and $|V|$ are voltage angle and magnitude respectively, and P, Q are bus powers. J_1 through J_4 are system Jacobian sub-matrices.

Economic dispatch problem for N generator system [16]:

Minimize $C_t = \sum_{i=1}^{N} C_i(P_{gi})$; subject to: $\sum_{i=1}^{n} P_{gi} = P_L + P_D$

Where $C_i = \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i$.

C_i is the fuel cost function and P_{gi} is the power output of unit i. α_i, β_i, and γ_i are quadratic cost function parameters. C_t is the total cost, while P_L and P_D are the total loss and demand respectively.

Unit commitment problem for generators over k intervals [16-18]:

$$F_{i*}(k) = \min_{\{x_j(k+1)\}} \{P_{i*}(k) + T_{i*,j}(k) + F_j(k+1)\}$$

$P_i(k)$ is the minimum production cost of combination $X_i(k)$. $T_{ij}(k)$ is the cost of transition from combination $x_i(k)$ to combination $x_j(k+1)$ between intervals k and $(k-1)$. x_{i*} is the best combination for a given stage (or interval).

References

1. A. G. Phadke, "Power Engineering Education: Crisis Revisited," *IEEE Computer Applications in Power*, vol. 15, n 4, pp. 12-15, Oct. 2002.

2. G. G. Karady, G. T. Heydt, M. Michel, P. Crossley, H. Rudnick, S. Iwamoto, "Review of electric power engineering education worldwide," *Proc. 1999 IEEE Power Engineering Society Summer Meeting*, vol. 2, pp. 906 – 915.

3. P. Idowu, "In search of a perfect power engineering program," *IEEE Trans. Education*, vol. 47, n 3, pp. 410-414, Aug. 2004.

4. A. Rugarcia, R. M. Felder, D. R. Wood, J. E. Stice, "The Future of Engineering Education I. A Vision for a New Century," *Chemical Engineering Education*, vol. 34, n 1, pp. 16-25, 2000.

5. R. M. Felder, D. R. Woods, J. E. Stice, E. James, and A. Rugarcia, "The Future of Engineering Education II. Teaching Methods that Work," *Chemical Engineering Education*, vol. 34, n I, pp. 26-39, 2000.

6. M. Kezunovic, A. Abur, H. Garng, A. Bose, K. Tomsovic, "The role of digital modeling and simulation in power engineering education," *IEEE Trans. Power Systems*, vol. 19, n 1, pp. 64 – 72, Feb. 2004.

7. P. Idowu, "Development of a prototype resource optimizing, access delimited (ROAD) laboratory," *Proc. 2000 IEEE Power Engineering Society Winter Meeting*, vol. 2, pp. 1405-1409.

8. M. M. Albu, K. E. Holbert, G. T. Heydt, S. D. Grigorescu, V. Trusca, "Embedding Remote Experimentation in Power Engineering Education," *IEEE Trans. Power Systems*, vol. 19, n 1, pp. 139-143, Feb. 2004.

9. M. Varano, M. Patel, D. Asnani, A. TsyKalyuk, P. Idowu, "Basics of Energy Systems through Games," *Proc. NAPS 2006. 38th North American Power Symposium*, pp. 371-374, Sept. 2006.

10. G. G. Karady, K. E. Holbert, "Novel Technique to Improve Power Engineering Education Through Computer-Assisted Interactive Learning," IEEE Trans. Power Systems, vol. 19, n 1, pp. 81-87, Feb. 2004.

11. S. Suryanarayanan, E. Kyiakides, "An Online Portal for Collaborative Learning and Teaching for Power Engineering Education," *IEEE Trans. Power Systems*, vol. 19, n 1, pp. 73-80, Feb. 2004.

12. MATLAB® The MathWorks, Inc. 3 Apple Hill Drive, Natick, MA 01760-2098, United States

13. *Positive Sequence Load Flow*, GE Energy (January 5, 2008) [Online]. Available: http://www.gepower.com/prod_serv/products/utility_software/en/ge_pslf/.

14. J. Yang, M. Anderson, "PowerGraf: an educational software package for power systems analysis and design," *IEEE Trans. Power Syst.*, vol.13, pp.1205-1210, Nov. 1998.

15. *PowerWorld Simulator 13*, PowerWorld Corporation (January 3, 2008) [Online]. Available: http://www.powerworld.com/.

16. Hadi Saadat, *Power System Analysis,* New York: McGraw-Hill, 1999.

17. John Grainger and William Stevenson, *Power System Analysis*, New York: McGraw-Hill, 1994.

18. Allen J. Wood and Bruce F. Wollenberg, *Power Generation, Operation, and Control*, 2nd edition, John Wiley and Sons, Inc., 1996. pp. 131-160.

Biographical Information

Peter Idowu received the Ph.D. degree from the University of Toledo, Toledo, OH, in 1989. He is currently an Associate Professor of Electrical Engineering and Director of Graduate Programs at the School of Science, Engineering and Technology, Penn State University – Harrisburg, Middletown, PA. His research interests include modeling, simulation and control of electric machines, power systems, and remote laboratory systems. Dr. Idowu is a registered Professional Engineer in the State of Ohio.

Mohamed Omer received his BSEE and M.Eng. EE degrees from Penn State University – Harrisburg, PA in 2006 and 2008 respectively. He is currently an Electrical Engineer with Pennsylvania Power Light (PPL), Allentown, PA.

USING COMPUTATIONAL SOFTWARE ROOT SOLVERS: A NEW PARADIGM FOR PROBLEM SOLUTIONS?

B. K. Hodge and Rogelio Luck
Mechanical Engineering Department
Mississippi State University
Mississippi State, MS 39762

Abstract

Many of the "procedures" for solving engineering problems are formulations to solve an algebraic equation or a system of algebraic equations—to extract roots. Computational software systems, such as Mathcad, Mathematica, Matlab, and EES, make possible "direct" solutions of root-finding problems in which the solution procedure is transparent to the user. These computational systems permit a unified approach, a "new" paradigm, to be used for the solution to many engineering problems. The unified approach consists of three steps: (1) formulate a well-posed system of algebraic equations, (2) use a computational system root solver to do the "arithmetic," and (3) verify the results. This paper explores the use of the unified approach for mechanical engineering problems and investigates the pedagogical inferences of the unified approach using computational software systems in undergraduate mechanical engineering education. The unified approach permits the student to focus more on the engineering aspects of a problem than the "arithmetic" aspects. With less time spent on arithmetic, more time is available for students to engage is higher-level synthesis and understanding. Although the examples in this paper are appropriate for mechanical engineering, the paradigm is transferable to any engineering discipline in which problem formulations result in systems of equations.

Introduction

Many of the "procedures" for solving engineering problems are formulations to solve an algebraic equation or a system of algebraic equations—to extract roots. In general, an algebraic equation can be linear or nonlinear and a system of algebraic equations can contain both linear and nonlinear algebraic equations. Recent computational software systems, such as Mathcad, Mathematica, Matlab, and EES, have made possible "direct" solutions of such problems in which the sometimes-laborious task, the procedure, of obtaining the solution is transparent to the user. Such equation or root solvers allow the students to concentrate on the engineering aspects of the problem, sparing them from being preoccupied by the details of finding the roots; i.e., solving the equations. The students can then focus their efforts on applying their engineering knowledge and skills to obtain a system of equations that represents the problem and that is sufficiently descriptive to provide a solution; i.e., to obtain a well-posed system of equations. An additional pedagogical advantage of using the root solvers is that the students are forced to discern whether the numerical (or symbolic) answers provided by the equation solvers are reasonable. Thus, the advent of such computational systems permits a unified approach, a "new" paradigm, to be used for the solution to many engineering problems. For appropriate problems, the unified approach consists of three steps: (1) formulate a well-posed system of algebraic equations, (2) use a computational system root solver to do the "arithmetic," and (3) verify the results.

Computational systems provide robust root solvers for systems of algebraic equations. Reference 1, from NIST, presents a concise summary of capabilities of the commonly used computational systems. The "solve-block" structure in Mathcad, for example, requires the identification of the system of equations, values of the known quantities, and initial guessed values for the unknowns to obtain the solution. This is in stark contract to line-by-line coding of a root-solver procedure (Newton-Raphson, for instance) in a higher-level language (FORTRAN or C) to solve such a system.

The purposes of this paper are twofold: (1) to explore the use of the unified approach using computational software systems for mechanical engineering problems and (2) to investigate the pedagogical inferences of use of the unified approach with a computational software system in undergraduate mechanical engineering education. From a pedagogical standpoint, the unified approach permits the student to focus more on the engineering aspects than the arithmetic aspects.

Consider the following diverse examples using the computational system, Mathcad. All examples will be solved utilizing the three-step unified approach: (1) formulate the solution as a well-posed system of algebraic equations, (2) use the root solver to do the "arithmetic," and (3) verify the results. Example will be presented for an engineering economics problem, a vibrations problem, a pipe flow problem, a mechanics of machinery problem, and a cooling/bypass loop simulation. Although Mathcad is the computational software system used in this paper, other computational software systems possess similar capabilities and could be used equally well.

Examples

Engineering Economics

A simple example to illustrate the unified approach is provided by the capital recovery factor of the present worth of a uniform series

$$\frac{A}{P}=\frac{\frac{i}{m}\left(1+\frac{i}{m}\right)^{mn}}{\left(1+\frac{i}{m}\right)^{mn}-1} \qquad (1)$$

where A is the payment at intervals of m cycles during n years, P is the principal, and i is the interest rate per year. The quotient A/P is the capital recovery factor. Tabular values of the capital recovery factor are provided in many engineering economy textbooks, but the unified approach yields solutions without table interpolations. Consider the following example.

Example 1:

(a) If $20,000 is borrowed for 4 years, what interest rate is required for monthly payments of $500?
(b) What principal could be borrowed at an interest of 6 percent and monthly payments of $500 for 4 years?

Solution:

The solution is provided in Figure 1, the Mathcad worksheet. The solutions for Parts (a) and (b) are illustrated in Parts (a) and (b), respectively, of Figure 1. For both solutions, the Mathcad solve block structure of Mathcad is used. The solve block is initiated by a Given and is terminated by a Find statement that specifies the unknowns. In this case, a single equation, Equation (1), with four variables is included within the solve block. The solve block can be used to solve for one of the variables, given the remaining three. Thus, Parts (a) and (b) of the problem are similar; the only difference being the variable specified in the Find statement. Essentially, all problems involving the present worth of a uniform series can be solved using this same solve block and specifying the appropriate unknown in the Find statement.

Verification:

Verification for this example consists of observing that for both parts of Example 1, the "numbers" are similar to what might be encountered in securing a car loan. The results are what might be expected, so the first verification test is that the results are not irrational. A more precise verification is provided in Part (c) of Figure 1. In Part (c) of the figure, a function, A(i,P,m,n), expressing the functional relationship for the capital recovery factor of the present worth of a uniform series is defined and the results are verified by substituting i and P, respectively, into the function to recover the monthly payment, A. In both cases, the function returns the appropriate value.

$P := 21000 \quad n := 4 \quad A := 500 \quad m := 12$ Define known quantities

$i := 2\%$ Initial guess on interest rate

Given

$$A = P\cdot\frac{\frac{i}{m}\cdot\left(1+\frac{i}{m}\right)^{m\,n}}{\left(1+\frac{i}{m}\right)^{m\,n}-1}$$

$i := \text{Find}(i) \qquad i = 6.705\%$

(a) Solution to Part (a)

$i := 6\% \quad n := 4 \quad A := 500 \quad m := 12$ Define known quantities

$P := 1000$ Initial guess on principal

Given

$$A = P\cdot\frac{\frac{i}{m}\cdot\left(1+\frac{i}{m}\right)^{m\,n}}{\left(1+\frac{i}{m}\right)^{m\,n}-1}$$

$P := \text{Find}(P) \qquad P = 21290.159$

(b) Solution to Part (b)

$$A(i,P,m,n) := P\cdot\frac{\frac{i}{m}\cdot\left(1+\frac{i}{m}\right)^{m\,n}}{\left(1+\frac{i}{m}\right)^{m\,n}-1}$$

$A(6.705\%,21000,12,4) = 500.002$ Part (a)

$A(6\%,21290,12,4) = 499.996$ Part (b)

(c) Verification of Solutions

Figure 1. Solutions for Example 1.

Vibrations

The normalized amplitude, Amp, of the vibration of the door panel of an automobile is given by

$$Amp = \frac{1}{\sqrt{\left[1-\left(\frac{\omega}{\Omega_f}\right)^2\right]^2 + c^2 \cdot \left(\frac{\omega}{\Omega_f}\right)^2}} \qquad (2)$$

where c is the damping coefficient, ω is speed of the engine, and Ω_f is the natural frequency of vibration of the door panel.

Example 2:

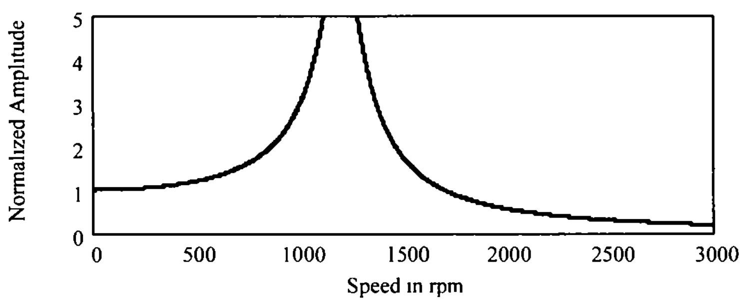
Find the speed of the engine for which the normalized amplitude is 2 for $\Omega_f = 20$ Hz.

Solution:

The solution steps are illustrated in Figure 2. Figure 2(a) is a plot of the normalized amplitude as a function of motor speed in rpm. The function is double valued in rpm for a specified value of the normalized amplitude. The solution is presented in Figure 2(b). Part (a) of the figure indicates that a normalized amplitude of 2 occurs at about 750 rpm and at about 1500 rpm. These values are used as initial guesses in the Mathcad solve block in Part (b) of Figure 2. The normalized amplitude function is defined and then used in the solve block. The results are 858 rpm and 1453 rpm.

Verification:

The results presented in Figure 2(b) agree with the graphical representation in Figure 2(a).



(a) Plot of Normalized Amplitude as a Function of Engine Speed (rpm)

$$\mathrm{Amp}(\omega, c, \Omega_f) = \frac{1}{\sqrt{\left[1-\left(\frac{\omega}{\Omega_f}\right)^2\right]^2 + c^2\left(\frac{\omega}{\Omega_f}\right)^2}}$$

$c := 0.15 \qquad \mathrm{Hz} = 60 \cdot \mathrm{rpm} \qquad \Omega_f = 20 \cdot \mathrm{Hz} \qquad \omega := \begin{pmatrix} 750 \\ 1500 \end{pmatrix} \cdot \mathrm{rpm}$

Given

$2 = \mathrm{Amp}(\omega, c, \Omega_f)$

$\mathrm{Speed} := \mathrm{Find}(\omega) \qquad \mathrm{Speed} = \begin{pmatrix} 89.887 \\ 152.144 \end{pmatrix} \mathrm{Hz} \qquad \mathrm{Speed} = \begin{pmatrix} 858.355 \\ 1452.869 \end{pmatrix} \mathrm{rpm}$

(b) Mathcad Worksheet

Figure 2. Solution for Example 2.

Pipe Flow

Piping systems are ubiquitous in engineering systems and are characterized as series, parallel, or network. Hodge (2) explored the unified approach to solving a variety of piping systems problems. Included in Reference 2 are series, parallel, and network examples. The example presented herein is different from any of those in Reference 2.

The unified approach to piping systems uses the energy equation [Hodge and Taylor (3)], cast between two stations in a pipe with a pump as the fundamental building block,

$$\frac{P_A - P_B}{\gamma} = Z_B - Z_A + \frac{V^2}{2g}\left(f\frac{L}{D} + K + C \cdot f_T\right) - W_s \frac{g_c}{g} \quad (3)$$

where W_s is the increase in head of the pump and K and C are the minor loss coefficients. In addition, conservation of mass and uniqueness of pressure at a point are invoked. The conventional solution "procedures" developed for any characterization of piping problem satisfy these principles either by formally applying them in as part of the problem formulation or by using them in a specified iterative sequence—the "procedure." Solutions for <u>all</u> series, parallel, and network hydraulic piping problems can be formulated as solutions to a non-linear equation or to a system of nonlinear algebraic equations.

In Equation (1), expressions for the friction factor and fully-rough friction factor, f_T, are needed. In the laminar regime, the usual expression is

$$f = \frac{64}{\mathrm{Re}_D} \quad (4)$$

Several different representations are available for turbulent flow. In this paper the representation of Haaland (4) is used.

$$f = \frac{0.3086}{\left[\log\left(\left(\frac{\varepsilon}{3.7D}\right)^{1.11} + \frac{6.9}{\mathrm{Re}_D}\right)\right]^2} \quad (5)$$

Minor loss terms are sometimes expressed as equivalent lengths using the fully-rough friction factor, f_T, the asymptotic value of the friction factor for a given relative roughness. From the Haaland equation, the fully-rough friction factor becomes

$$f_T = \frac{0.3086}{\left[\log\left(\left(\frac{\varepsilon}{3.7D}\right)^{1.11}\right)\right]^2} \quad (6)$$

With the aforementioned as the basis for piping system problem solution formulation, an example of the unified approach will be examined and discussed.

Example 3:

Water at 70 F is to be pumped from one reservoir to another reservoir located 20 ft above the first reservoir. A pump with a characteristic curve (increase in head versus the flow rate)

$$W_s = 403.33 - 0.127 \cdot Q + 0.004362 \cdot Q^2 - 0.000039 11 \cdot Q^3 \quad for \quad 0 < Q < 150 gpm \quad (7)$$

where W_s is in ft-lbf/lbm when Q is in gpm, is in the system. The system consists of 2000 ft of schedule 40 nominal 3-inch commercial steel pipe. Minor losses total K = 1000 and C = 0.
Find the flow rate the pump will produce in the system.

Solution:

The unified approach solution is provided in Figure 3. Much of the contents of the figure are specifying the system boundary conditions, the physical properties, the friction factor representation, and the units. As with the other examples, the solution is accomplished in the solve block. Prior to the solve block specification, initial estimates of the two unknowns, the pump increase in head and the flow rate, are provided. The pump characteristic equation, with appropriate units is defined as is the energy equation for the system. The Find statement contains the two unknowns. The pump increase in head and the flow rate, the pump-system operating point, are 393 ft-lbf/lbm and 105 gpm, respectively. A similar worksheet can be used to solve all series hydraulic piping problems by suitably modifying the solve block and the Find statement.

Verification:

The first point of verification is that the flow rate, 105 gpm, falls within the specified flow rate range of the pump. In Part (b) of Figure 3 the increase in head of the pump, PW_s, is computed from the pump characteristic curve given the operating point flow rate. The energy equation increase in head requirement, EW_s, is also computed. Both values are identical and are equal to the returned value, W_s, of the solution.

ORIGIN≡ 1 Reset counter from the default value of 0 to 1

Input the pipe geometry

Diameter in inches	Length in feet	Roughness in feet
$D := 3.068\,\text{in}$	$L := 2000\,\text{ft}$	$\varepsilon := 0.00015\,\text{ft}$

Input the system boundary (initial and end) conditions

Pressures in psi	Elevations in feet
$\begin{pmatrix} P_a \\ P_b \end{pmatrix} := \begin{pmatrix} 0 \\ 0 \end{pmatrix} \frac{\text{lbf}}{\text{in}^2}$	$\begin{pmatrix} Z_a \\ Z_b \end{pmatrix} := \begin{pmatrix} 0 \\ 20 \end{pmatrix} \text{ft}$

Input the loss coefficients

K factor	Equivalent length
$K := 1000$	$C := 0$

Input the fluid properties

Density in lbm/ft ^{3}	Viscosity in lbm/ft-s
$\rho := 62.3 \frac{\text{lb}}{\text{ft}^3}$	$\mu := 0.000658 \frac{\text{lb}}{\text{ft}\cdot\text{sec}}$

Define constants and adjust units for consistency

$$g := 32.174 \frac{\text{ft}}{\text{sec}^2} \qquad g_c := 32.174 \frac{\text{ft lb}}{\text{lbf sec}^2}$$

Define the functions for Reynolds number, fully-rough friction factor, and friction factor

$$Re(q,d) := \frac{4\cdot\rho\, q}{\pi\, d\, \mu} \qquad f_T(d,\varepsilon) := \frac{0.3086}{\left[\log\left[\left(\frac{\varepsilon}{3.7\,d}\right)^{1.11}\right]\right]^2}$$

$$f(q,d,\varepsilon) := \begin{cases} \dfrac{0.3086}{\left[\log\left[\dfrac{6.9}{Re(q,d)} + \left(\dfrac{\varepsilon}{3.7\,d}\right)^{1.11}\right]\right]^2} & \text{if } Re(q,d) > 2300 \\ \dfrac{64}{Re(q,d)} & \text{otherwise} \end{cases}$$

Figure 3. Mathcad Solution for Problem 3.

$W_s := 100\,\text{ft}\cdot\frac{\text{lbf}}{\text{lb}}$ (Initial guess of pump increase in head)

$Q := 50\cdot\frac{\text{gal}}{\text{min}}$ (Initial guess of flow rate.) $\text{gpm} := \frac{\text{gal}}{\text{min}}$

Given

$$W_s = \left[403.33 - 0.127\frac{Q}{\text{gpm}} + 0.004362\left(\frac{Q}{\text{gpm}}\right)^2 - 0.00003911\left(\frac{Q}{\text{gpm}}\right)^3\right]\cdot\frac{\text{ft}\cdot\text{lbf}}{\text{lb}}$$

$$W_s\cdot\frac{g_c}{g} = \frac{P_b - P_a}{\rho\, g}\cdot g_c + Z_b - Z_a + \frac{8}{\pi^2}\cdot\frac{Q^2}{g\cdot(D)^4}\cdot\left(f(Q,D,\varepsilon)\cdot\frac{L}{D} + K + C\cdot f_T(D,\varepsilon)\right)$$

$$\begin{pmatrix} W_s \\ Q \end{pmatrix} := \text{Find}(W_s, Q) \qquad W_s = 392.868\,\text{ft}\cdot\frac{\text{lbf}}{\text{lb}} \qquad Q = 104.887\frac{\text{gal}}{\text{min}}$$

(a) Solution

$$PW_s := \left[403.33 - 0.127\frac{Q}{\text{gpm}} + 0.004362\left(\frac{Q}{\text{gpm}}\right)^2 - 0.00003911\left(\frac{Q}{\text{gpm}}\right)^3\right]\cdot\frac{\text{ft}\cdot\text{lbf}}{\text{lb}}$$

$$PW_s = 392.868\,\text{ft}\cdot\frac{\text{lbf}}{\text{lb}}$$

$$EW_s := \left[\frac{P_b - P_a}{\rho\cdot g}\, g_c + Z_b - Z_a + \frac{8}{\pi^2}\,\frac{Q^2}{g\,(D)^4}\left(f(Q,D,\varepsilon)\cdot\frac{L}{D} + K + C\, f_T(D,\varepsilon)\right)\right]$$

$$EW_s = 392.868\,\text{ft}$$

(b) Verification

Figure 3. Mathcad Solution for Problem 3 (Concluded).

Mechanisms

The four-bar linkage represents a classic topic in virtually all mechanics of machinery courses. By using complex notation, two equations describing the spatial relationships of the links can be derived and the procedure discussed herein used to solve the system. Consider the following example.

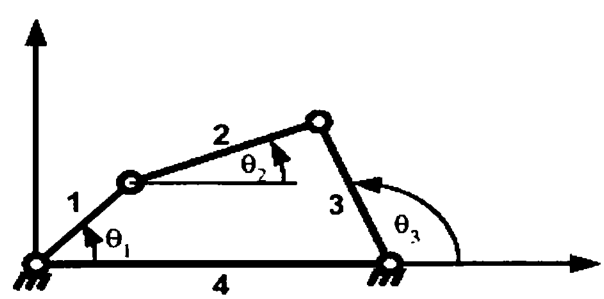


Figure 4. Four-bar Linkage Schematic.

Example 4:

The four-bar mechanism illustrated in Figure 4 has links 1, 2, 3, and 4 with unit lengths of 1, 2, 2, and 3, respectively. Link 4 is fixed to the x-axis and is not allowed to move. Find the angles θ_2 and θ_3 when the θ_1 is -30 degrees. Show the four-bar link arrangement in a fashion similar to that in Figure 4.

Solution:

By using Euler's Formula, i.e., polar notation or phasors, the links of the mechanism are related by the following relationship:

$$R_1 \cdot e^{j\theta_1} + R_2 \cdot e^{j\theta_2} + R_3 \cdot e^{j\theta_3} - R_4 = 0 \qquad (8)$$

Two equations can be obtained by equating the real and imaginary parts of Equation (8).

$$\begin{aligned} &R_1 \cdot \cos(\theta_1) + R_2 \cdot \cos(\theta_2) \\ &\quad + R_3 \cdot \cos(\theta_3) - R_4 = 0 \\ &R_1 \cdot \sin(\theta_1) + R_2 \cdot \sin(\theta_2) \\ &\quad + R_3 \cdot \sin(\theta_3) = 0 \end{aligned} \qquad (9)$$

The Mathcad solution is presented in Figure 5. Initial values are identified, and the solve block is used to find the two unknowns, θ_1 and θ_2. The spatial layout is then determined and plotted. In an extended version of this problem, the animation capability of Mathcad can be used to determine and illustrate the four-bar linkage motion for $0 < \theta_1 < 360$ degrees.

Verification:

The plot of the mechanism shows the relative length of links in the correct proportion since the x and y axes have the same scale. As expected, the plot shows that the angles $\theta_3 = -44\cdot\text{deg}$ and $\theta_2 = 70\cdot\text{deg}$ are reasonable values for the configuration of the four bar mechanism when the input $\theta_1 = -30\cdot\text{deg}$.

$R_1 := 1 \qquad R_2 := 2 \qquad R_3 := 2 \qquad R_4 := 3 \qquad \theta_1 := -\text{deg}\cdot 30$

$\theta_2 := 0 \qquad \theta_3 := 0$ Initial guesses:

Given

$$R_1\cdot\cos(\theta_1) + R_2\cdot\cos(\theta_2) + R_3\cdot\cos(\theta_3) - R_4 = 0$$

$$(R_1\cdot\sin(\theta_1) + R_2\cdot\sin(\theta_2) + R_3\cdot\sin(\theta_3)) = 0$$

$$\begin{pmatrix}\theta_2\\ \theta_3\end{pmatrix} := \text{Find}(\theta_2,\theta_3) \qquad \begin{pmatrix}\theta_2\\ \theta_3\end{pmatrix} = \begin{pmatrix}70\\ -44\end{pmatrix}\text{deg}$$

Graphing the four-bar linkage mechanism

$$A := \begin{pmatrix} 0 \\ R_1\cdot e^{j\cdot\theta_1} \\ R_1\cdot e^{j\cdot\theta_1} + R_2\cdot e^{j\cdot\theta_2} \\ R_4 \end{pmatrix}$$

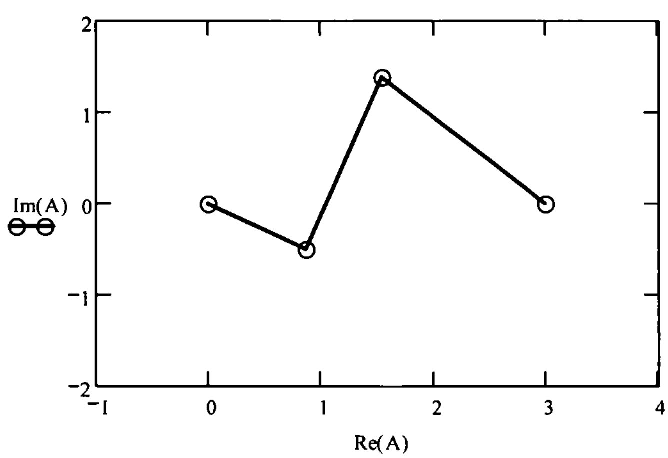


Figure 5. Solution of Example 4.

System Simulation

Systems of non-linear algebraic equations arise naturally in many steady-state system simulations. The use of computational system root solvers alleviates considerable programming effort and permits the student to concentrate on the engineering aspects of the problem. Consider the following thermal system simulation example.

Example 5

Characteristics and specifications for an oil cooler system are delineated below. A system schematic is provided in Figure 6.

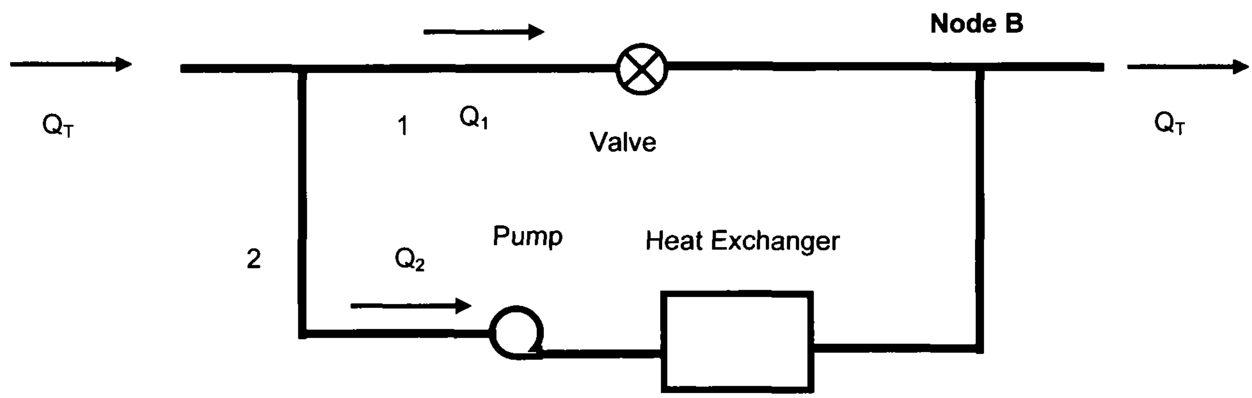


Figure 6. Schematic for Oil Cooler System.

System characteristics:

Line	D (sch 40, inch)	L (ft)
1	3 ½	100
2	3 ½	200

Oil properties (constant):

$\rho = 54.3$ lbm/ft^3 $\quad$ c = 0.48 Btu/lbm-F

$\nu = 9.8 \times 10^{-5}$ ft^2/sec $\quad T_{in} = 200$ F

Pump characteristic curve:

$$W_s = 214.2 + 0.05Q - 0.0005833Q^2 \quad \text{(Q in gpm)} \tag{10}$$

Water properties: mass flow rate = 30 lbm/sec

$T_{in} = 70$ F

Heat Exchanger: $\quad A = 400 \text{ ft}^2 \quad (11)$

$$HX = 0.0045Q^{1.9} \tag{12}$$

Determine the exit temperature of the oil.

Solution:

This solution to this system simulation problem involves both hydraulic and thermal considerations. If constant thermophysical properties are considered, the hydraulics and thermal solutions can be decoupled and the exit temperature calculated after the individual pipe flow rates are known. In this example, both the hydraulic and thermal portions will be worked in a single solve block. Lines 1 and 2 form a parallel network, so the total change in head for pipe 1 must be equal to the total change in head for pipe 2. The energy equation, as referenced in Example 3, is used to describe the changes in heads of the individual pipes. Once the pipe flow rates are known, the temperature of the oil exiting the heat exchanger can be determined. The determination of the temperature of the oil exiting the heat exchanger is a heat exchanger analysis problem and proceeds from capacity to NTU to effectiveness to rating to exit temperature. An energy balance must be performed at node B to determine the exit

Initial guesses for the unknowns are needed to use the solve block.

$Q_1 := 125 \cdot \frac{gal}{min}$ $\quad Re_1 := 100000$ $\quad C_{min} := 5 \cdot \frac{BTU}{sec \cdot R}$ $\quad K := 2.85$

$Q_2 := 125 \cdot \frac{gal}{min}$ $\quad Re_2 := 100000$ $\quad C := \frac{C_{min}}{C_{max}}$ $\quad \xi := 0.5$

$HP := 216 \cdot ft$ $\quad HX := 216 \cdot ft$ $\quad NTU := 2$ $\quad gpm := \frac{gal}{min}$

$U := 10 \cdot \frac{BTU}{hr \cdot ft^2 \cdot R}$ $\quad T_{out} := 130 \cdot F$ $\quad T_{exit} := 190 \cdot F$

The ***solve*** block equations are next defined.

Given

$Q_T = Q_1 + Q_2$ $\quad Re_1 = \frac{Q_1}{A_c} \cdot \frac{ID}{\upsilon}$ $\quad Re_2 = \frac{Q_2}{A_c} \cdot \frac{ID}{\upsilon}$

$$HX = 0.0045 ft \cdot \left(\frac{Q_2}{gpm} \right)^{1.9}$$

$$HP = 214.2 \cdot ft + 0.05 \cdot ft \cdot \frac{Q_2}{gpm} - 0.0005833 ft \cdot \left(\frac{Q_2}{gpm} \right)^2$$

$$\frac{1}{2 \cdot g \cdot A_c^2} \cdot (Q_1)^2 \cdot \left(K + f_f(Re_1) \cdot \frac{L_1}{ID} \right) = \frac{1}{2 \cdot g \cdot A_c^2} \cdot (Q_2)^2 \cdot f_f(Re_2) \cdot \frac{L_2}{ID} + HX - HP$$

$C_{min} = Q_2 \cdot \rho_{oil} \cdot c_{oil}$ $\quad C = \frac{C_{min}}{C_{max}}$

$$U = \frac{\frac{BTU}{hr \cdot ft^2 \cdot R}}{\left(\frac{5.75}{Re_2^{0.8}} \right) + 0.004} \qquad NTU = \frac{U \cdot A_{hx}}{C_{min}}$$

$$\xi = \frac{1 - \exp[-NTU \cdot (1 - C)]}{1 - C \cdot \exp[-NTU \cdot (1 - C)]} \qquad T_{out} = T_{in} - \xi \cdot (T_{in} - T_{water})$$

$$T_{exit} = \frac{Q_1}{Q_T} \cdot T_{in} + \frac{Q_2}{Q_T} \cdot T_{out}$$

$ans := Find(Q_1, Q_2, HX, HP, Re_1, Re_2, C_{min}, C, U, NTU, \xi, T_{out}, T_{exit})$

Figure 7. Solution of System Simulation Example

$$Q_1 := ans_0 \qquad Q_1 = 189.142\frac{gal}{min}$$

$$Q_2 := ans_1 \qquad Q_2 = 260.858\frac{gal}{min}$$

$$W_S := ans_3 \qquad W_S = 187.551ft$$

$$C := ans_7 \qquad C = 0.505$$

$$U := ans_8 \qquad U = 175.017\frac{BTU}{hr\cdot ft^2 R}$$

$$NTU := ans_9 \qquad NTU = 1.284$$

$$\xi := ans_{10} \qquad \xi = 0.642$$

$$T_{out} := ans_{11} \qquad T_{out} = 116.532F$$

$$T_{exit} := ans_{12} \qquad T_{exit} = 151.615F$$

Figure 7. Solution of System Simulation Example (Concluded).

temperature. An energy balance must be performed at node B to determine the exit temperature of the oil at it leaves the system. An energy balance at node B yields

$$T_{exit} = \frac{Q_1}{Q_T}\cdot T_1 + \frac{Q_2}{Q_T}\cdot T_2 \qquad (13)$$

Figure 7 delineates the Mathcad worksheet for the problem solution. The solve block contains 13 equations and the Find function is used to determine the 13 unknowns. The exit temperature for the conditions of the problem statement is 151.6 F. Other values of important variables are also presented in the figure.

Verification:
The solution values are all reasonable. If the individual equations describing the system are evaluated, all values are consistent.

Pedagogical Inferences and Conclusions

The purpose of this paper is to discuss a unified approach to solving many problems of engineering interest. In all the examples explored in this paper, the same three steps are used. The treatments of all the example problems are identical and emphasize the three steps: (1) formulate a well-posed system of algebraic equations, (2) use the root solver to do the "arithmetic," and (3) verify the the results. In this paper, the arithmetic has been accomplished by using the Solve-Find structure of Mathcad. Other computational software systems (Mathematics, Matlab,....) offer the same capability, albeit in different formats, but with the same results.

Anecdotally, students appreciate the attention to problem solution using the three-step unified approach. The use of Mathcad with its Solve-Find structure relieves the student from assimilating different numerical techniques ("procedures") to solve a non-linear equation or a system of non-linear equations. The net result is that more involved and more realistic problems can be assigned. With less time spent on arithmetic, more time is available for students to engage is higher-level synthesis and understanding.

References

1. ______, "Guide to Available Mathematical Software," NIST, available at www.gams.nist.gov.

2. Hodge, B. K., 2006, "A Unified Approach to Piping System Problems," ASEE Computers in Education Journal, to appear in Vol. 2.

3. Hodge, B. K., and Taylor, R. P., 1999, Analysis and Design of Energy Systems, 3rd ed, Prentice-Hall, Upper Saddle River, NJ.

4. Haaland, S. E., 1983, "Simple and Explicit Formulas for the Friction Factor in Turbulent Flow," Trans. ASME, J. of Fluids Engineering, Vol. 103, No. 5, pp. 89-90.

Biographical Information

B. K. Hodge is a Professor of Mechanical Engineering at Mississippi State University (MSU) where he serves as the TVA Professor of Energy Systems and the Environment and is a Giles Distinguished Professor and a Grisham Master Teacher. He is a Fellow of the American Society for Engineering Education and the American Society of Mechanical Engineers and an Associate Fellow of the American Institute of Aeronautics and Astronautics.

Rogelio Luck received the B.S. degree from Texas Tech University in 1984, and the M.S. and Ph.D. degrees from Penn State Univ., University Park, in 1987 and 1989, respectively, all in Mechanical Engineering. In 1989 he joined the faculty at the Mechanical Engineering Dept. at Mississippi State University. His current research interest is in the area of simulation, optimization and control of building cooling heating and power. He has published in the areas of building cooling heating and power, uncertainty analysis, inverse heat transfer, radiation heat transfer, applied math, theoretical and applied control systems, piezoelectric sensors, electrical power system generation and distribution, and redundant measurement systems.

THE SPEED OF SOUND IN STEAM

Edwin G. Wiggins
Webb Institute

Introduction

In their junior year at Webb Institute, students learn about compressible flow. Instruction begins with coverage of isentropic flow of an ideal gas but quickly progresses to the isentropic flow of steam. Ultimately, students learn to do the conceptual design of a steam turbine. Steam is a bit difficult to deal with, because the speed of sound in this medium is a function of both temperature and pressure. There are Mathcad add-in functions that calculate many properties of steam, but the add-in package used at Webb Institute does not include a speed of sound function. For ideal gases, the speed of sound is given by the well know equation

$$c = \sqrt{kRT} \quad [1]$$

where k is the specific heat ratio, R is the specific gas constant, and T is the absolute temperature. However, this equation is not valid for steam.

This paper presents a simple method for finding the speed of sound in steam that is an extension of the existing steam property functions.

The Theory

Early in the derivation of equation [1], the continuity equation and the momentum equation are combined to produce the following

$$c = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s} \quad [2].$$

It is important to note that this equation is not restricted to ideal gases. It is this equation that forms the basis for using Mathcad to find the speed of sound in steam.

The set of steam functions for Mathcad includes functions for calculating specific volume and entropy based on pressure and temperature. While it is not possible to take partial derivatives in Mathcad, it is possible to construct a finite difference approximation to such a derivative. Thus

$$c \approx \sqrt{\left(\frac{P_2 - P_1}{\rho_2 - \rho_1}\right)_s} \quad [3]$$

where states 1 and 2 must be fairly close together, and they must have the same entropy.

Implementation in Mathcad

Figure 1 shows the Mathcad worksheet that calculates the speed of sound. The calculations performed by this worksheet are explained below, but users of the worksheet need not concern themselves with these calculations. Working in his or her own Mathcad worksheet, the user need only click Reference from Mathcad's Insert menu, browse to the location of the sound speed worksheet, and select it. Once this is done, the user's own worksheet will calculate the speed of sound in steam from the following syntax

c=sound(P,T). [4]

Behind the scenes, the sound speed worksheet performs the following steps: The first two equations in Figure 1 calculate the entropy and density at the pressure and temperature entered by the user. This is state 1. The third equation increments the pressure by 5 psi, and the fourth equation sets the entropy at the new state equal to the original entropy. Thus state 2 is at the same entropy as state 1 with a pressure 5 psi higher than state 1. The fifth and sixth equations calculate the density and temperature at state 2, and the final equation calculates the speed of sound averaged over the range from state 1 to state 2.

The Mathcad worksheet shown in Figure 1 makes use of several add-in steam property functions. A word about their syntax is in order. All such functions begin with "stm_". The first letter following the underscore is the function's output variable, and the next two letters indicate the input variables. Input variables must be made dimensionless, and the proper units must be attached to the output variable. Extensive use has also been made of Mathcad functions, as distinct from steam property functions. Since the user selects only the temperature and pressure at point 1, the Mathcad functions all have P_1 and T_1 as arguments. This is true even when properties are being calculated at state 2. State 2 is defined in terms of state 1 by incrementing the pressure by 5 psi at constant entropy. For example, the assignment statement

$$s_1(P_1,T_1) := stm\_spt\left(\frac{P_1}{psi}, T_1/{}^{\circ}F\right)\frac{BTU}{lbm \cdot R} \qquad [5]$$

calculates the entropy at state 1 from the values of P_1 and T_1. The values of P_1 and T_1 have been made dimensionless, and the units of entropy have been attached. The expression to the left in the assignment statement above is a Mathcad function, while the expression to the right is a steam property function.

Considerable experimentation was involved in finding the appropriate pressure increment. Too small a value gives unreliable results because of the small but finite uncertainty in the specific volume and entropy functions. Too large an increment gives a result that is averaged over too large an interval.

Values calculated by the worksheet shown in Figure 1 were carefully compared with values from the National Institute for Standards and Technology (NIST) Standard Database 12.[1]

The NIST values were obtained from the database by means of the REFPROP software. Figures 2 through 5 show comparisons of values for temperatures ranging from 600°F to 950°F at four different pressures. Agreement is clearly excellent. The dashed lines, which represent values calculated by Mathcad, are nearly superimposed on the solid lines, which represent values from NIST REFPROP. The standard deviation of all 32 data points is 2.74 feet per second, and the largest difference is 7 feet per second at 1200 psia, 600°F.

Conclusions

The Mathcad worksheet that calculates the speed of sound in steam is accurate and easy to use. Students at Webb Institute use this worksheet as a tool in doing the conceptual design of a steam turbine, where it is important to ensure that flow remains subsonic.

References

1. NIST Standard Reference Database 12 Version 5.2, 2005.

Biographical Information

Edwin G. Wiggins holds BS, MS, and Ph.D. degrees in chemical, nuclear, and mechanical engineering respectively from Purdue University. He is the Mandell and Lester Rosenblatt Professor of Marine Engineering at Webb Institute in Glen Cove, NY. Ed is a past chairman of the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers (SNAME) and a past regional vice president of SNAME. As a representative of SNAME, Ed Wiggins served on the Technology Accreditation Commission, the Engineering Accreditation Commission, and the Board of Directors of the Accreditation Board for Engineering and Technology (ABET). A Centennial Medallion and a Distinguished Service Award recognize his service to SNAME.

This worksheet contains the functions that calculate the speed of sound in steam when given the temperature and pressure.

$$s_1(P_1,T_1) := \text{stm\_spt}\left(\frac{P_1}{psi}, T_1/°F\right)\frac{BTU}{lbm \cdot R}$$

The entropy at P1, T1

$$\rho_1(P_1,T_1) = \frac{1}{\text{stm\_vpt}\left(\frac{P_1}{psi}, T_1/°F\right)\frac{ft^3}{lbm}}$$

The density at P1, T1

$$P_2(P_1) = P_1 + 5psi$$

Increment the pressure

$$s_2(P_1,T_1) = s_1(P_1,T_1)$$

Keep the entropy the same

$$T_2(P_1,T_1) := \text{stm\_tps}\left(\frac{P_2(P_1)}{psi}, s_2(P_1,T_1)\cdot\frac{lbm \cdot R}{BTU}\right)°F$$

The temperature at state 2

$$\rho_2(P_1,T_1) := \frac{1}{\text{stm\_vpt}\left(\frac{P_2(P_1)}{psi}, T_2(P_1,T_1)/°F\right)\frac{ft^3}{lbm}}$$

The density at state 2

The speed of sound is the square root of the partial derivative of pressure with respect to density at constant entropy. The equation below approximates that calculation.

$$\text{sound}(P_1,T_1) := \sqrt{\frac{P_2(P_1) - P_1}{\rho_2(P_1,T_1) - \rho_1(P_1,T_1)}}$$

Figure 1. Mathcad Worksheet

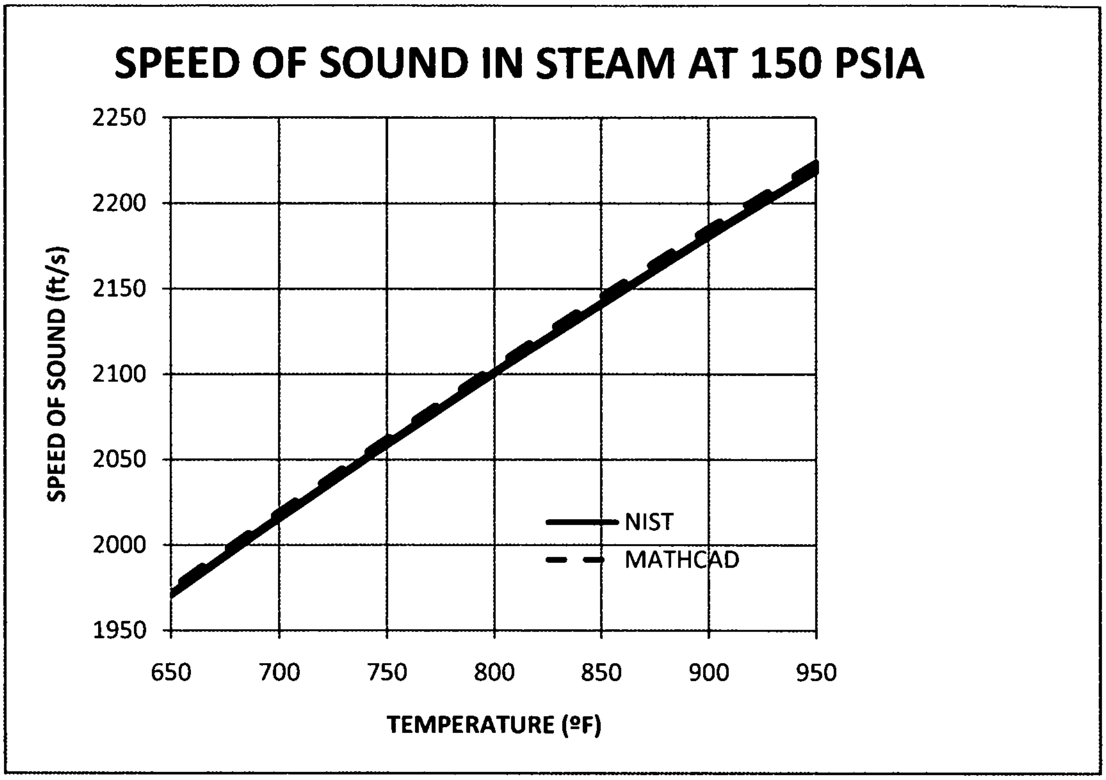


Figure 2. Sound Speed Comparison at 150 psia.

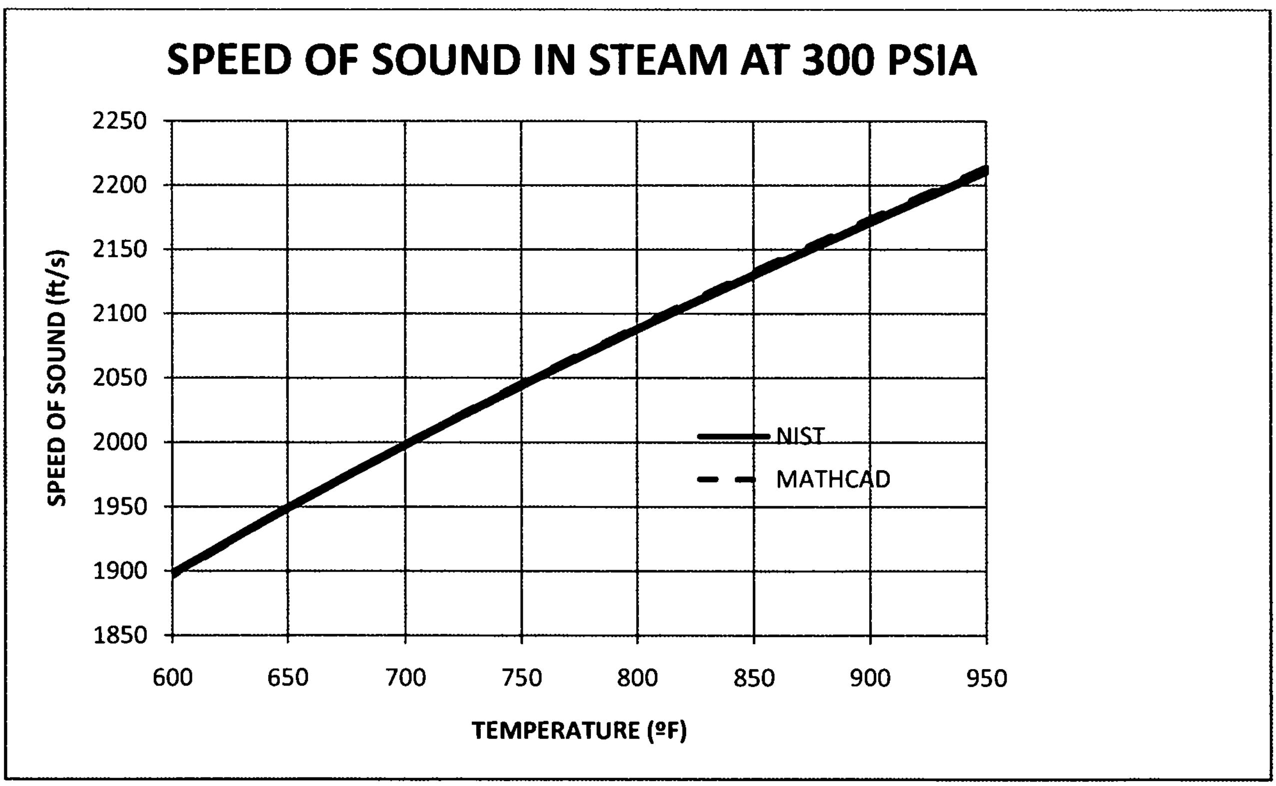


Figure 3. Sound Speed Comparison at 300 psia.

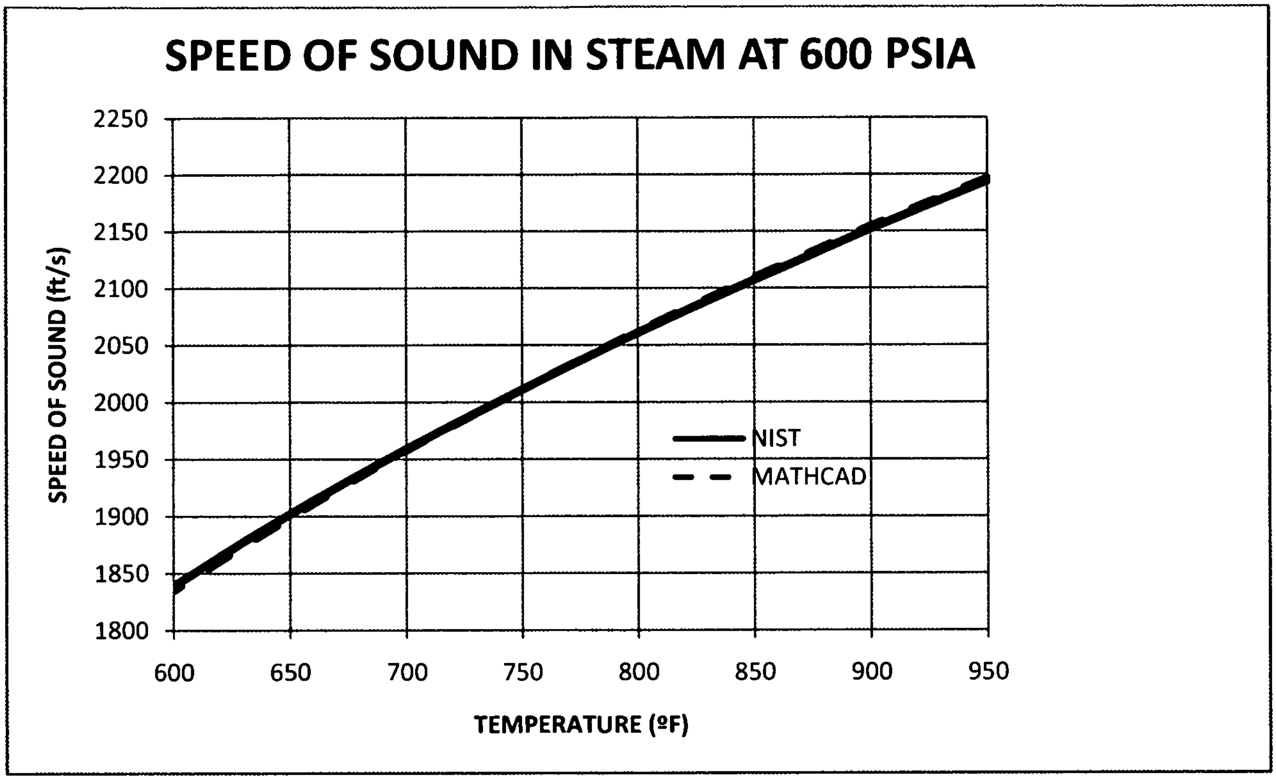


Figure 4. Sound Speed Comparison at 600 psia.

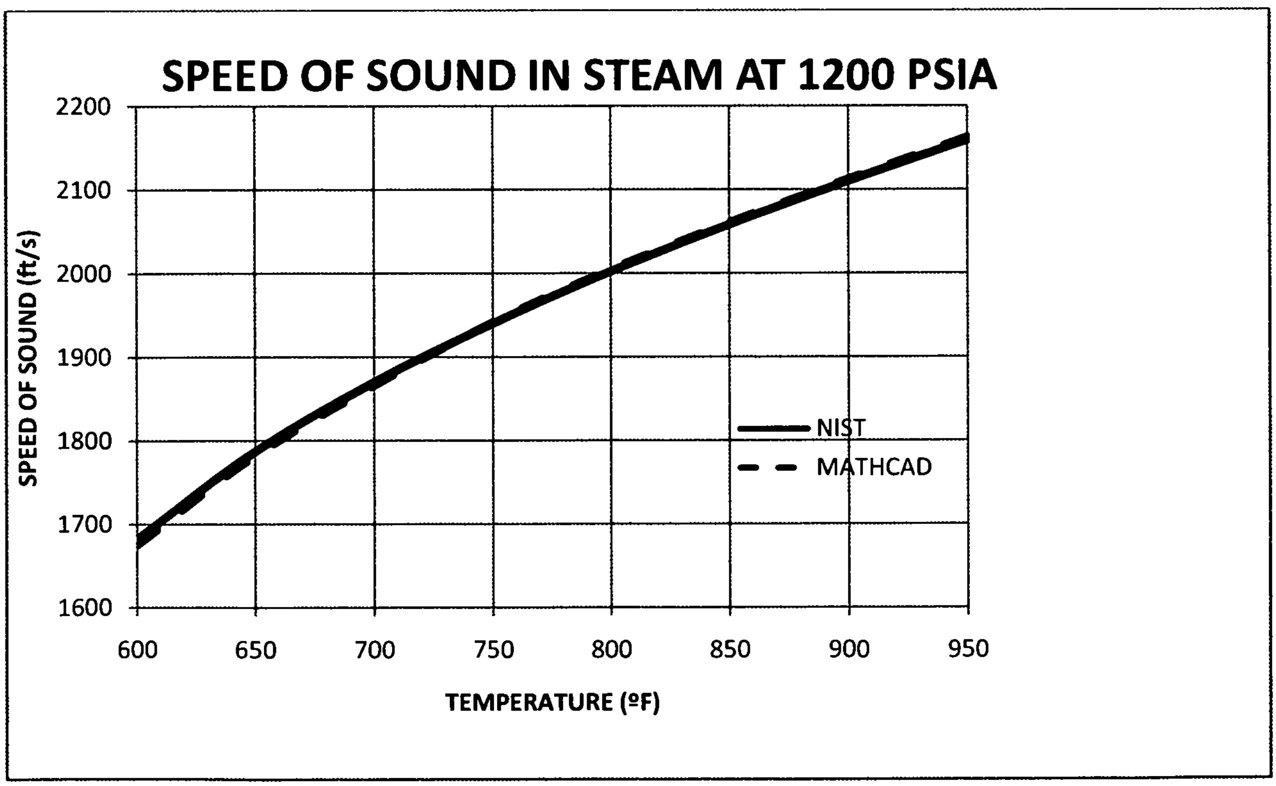


Figure 5. Sound Speed Comparison at 1200 psia.

FOURIER TRANSFORMS IN ARBITRARY DIMENSION

John L. Tiglias and Marvin Bishop
Department of Mathematics/Computer Science
Manhattan College
Manhattan College Parkway
Riverdale, New York 10471

Abstract

Fourier Transforms are an important element of undergraduate training in various engineering and scientific fields. This article presents a general derivation of the Fourier Transform for arbitrary dimension. It is shown that Fourier Transforms in even dimensions entail Bessel functions. Then data sets from Monte Carlo simulations for two and four dimensional systems are used to numerically perform the appropriate Fourier Transforms. Such activities expose students to both special functions and numerical methods of integration.

Introduction

In a previous article [1] in this journal we have presented derivations and applications of the Fourier Transform in one and three dimensions. In the present paper we extend this work to arbitrary dimension. It is found that Bessel functions [2, 3] are involved when taking the Fourier Transform in even dimensions. Bessel functions occur in many two dimensional engineering and physics applications such as heat conduction and electromagnetic wave propagation in waveguides of circular cross-section.

The general form of the Fourier transform [4, 5, 6] in any spatial dimension, D, of a function, $F(|\mathbf{R}|)$, which is symmetric in angular coordinates is given by

$$\tilde{F}(|\mathbf{K}|) = \int e^{i\mathbf{K}\cdot\mathbf{R}} F(|\mathbf{R}|)\, \mathbf{dR} \qquad (1)$$

where $\mathbf{K}$ is the wave-vector, $\mathbf{K}\cdot\mathbf{R}$ is the vector dot product between $\mathbf{K}$ and $\mathbf{R}$, $\mathbf{dR}$ is the appropriate volume element in D dimensional space and | | denotes the magnitude of a vector. In order to simplify the equations we will use bold on a variable to indicate a vector and ordinary text to indicate a vector magnitude.

In two dimensions the volume element in Eq. 1 in Cartesian coordinates is dxdy. If integration is performed employing Cartesian coordinates, two separate one dimensional integrals must be calculated. However, if the problem under investigation has angular symmetry (as is usually the case in many problems), polar coordinates can be employed to reduce the integral over two components, x and y, to a single integral. Then we are left with a one dimensional integral which will be simpler to handle both analytically and numerically than two different component integrals in x and y.

The volume element in polar coordinates is $\mathbf{dR}$ = RdRdθ. Then the Fourier Transform is given by

$$\tilde{F}(K) = \int_0^\infty \int_0^{2\pi} e^{iKR\cos\theta} F(R)\, d\theta\, R dR \qquad (2)$$

But the zero-th order Bessel function, $J_0(KR)$, is defined [2, 3] as

$$J_0(KR) = (1/2\pi) \int_0^{2\pi} e^{iKR\cos\theta}\, d\theta \qquad (3)$$

Hence,

$$\tilde{F}(K) = 2\pi \int_0^\infty J_0(KR)\, F(R)\, R\, dR \qquad (4)$$

This relationship is often called the Hankel Transform in the literature.

To reduce the general D dimensional case, which involves D component integrals, to a single integral over the magnitude of **R** one needs to relate the Cartesian coordinates of **R** to its D dimensional spherical coordinates expressed by $|\mathbf{R}|$ and D -1 angles $\theta_1\ \theta_2 \ldots \theta_{D-1}$. The resulting infinitesimal solid angle, **de**, is given by [7]

$$\mathbf{de} = \prod_{k=1}^{D-1} \sin^{k-1}\theta_k\, d\theta_k \qquad (5)$$

Then the surface area of a D dimensional sphere would be

$$\Omega_D = \int R^{D-1}\,\mathbf{de} \qquad (6a)$$

$$= R^{D-1}\int_0^{2\pi} d\theta_1 \int_0^{\pi} \sin\theta_2\, d\theta_2 \int_0^{\pi} \sin^2\theta_3\, d\theta_3 \ldots$$

$$\int_0^{\pi} \sin^{D-2}\theta_{D-1}\, d\theta_{D-1} \qquad (6b)$$

or

$$\Omega_D = 2\,\pi^{D/2} R^{D-1} / \Gamma(D/2) \qquad (7)$$

Here, Γ is the Gamma function [3]

$$\Gamma(x) = \int_0^{\infty} t^{x-1}\, e^{-t}\, dt \qquad (8)$$

Eq. 7 follows from the trigonometric integral [7]

$$\int_0^{\pi} \sin^N\theta\, d\theta = \Gamma((N+1)/2)\,\Gamma(1/2)\, / \,\Gamma(N/2+1) \qquad (9)$$

Then Eq. 1 becomes

$$\tilde{F}(|\mathbf{K}|) = [\,2\,\pi^{(D-1)/2} / \Gamma((D-1)/2)\,]$$

$$\int_0^{\infty} R^{D-1}\, F(R)\, dR \int_0^{\pi} e^{iKR\cos\theta} \sin^{D-2}\theta\, d\theta \qquad (10)$$

Here we have integrated over one less angle because of the cosine term in the exponential from the dot product. The angular integration can be expressed [6] in terms of the (D / 2 - 1) -th order Bessel function, $J_{D/2-1}(KR)$:

$$\int_0^{\pi} e^{iKR\cos\theta} \sin^{D-2}\theta\, d\theta = [2^{D/2-1}\Gamma(1/2)\Gamma((D-1)/2)]\; J_{D/2-1}(KR) / (KR)^{D/2-1} \qquad (11)$$

Using Eq. 11 in Eq. 10 one obtains

$$\tilde{F}(|\mathbf{K}|) = [\,(2\pi)^{D/2} / K^{(D-2)/2}]\int_0^{\infty} R^{D/2}\, F(R)\, J_{D/2-1}(KR)\, dR \qquad (12)$$

Eq. 12 is the generalized D dimensional Fourier transform.

When D = 2, Eq. 12 reduces to Eq. 4 and when D = 4, Eq. 12 will involve the first order Bessel function, $J_1(KR)$. The one dimensional integrals required for the Fourier Transform can be handled with either the integration facilities of software packages such as Maple or Mathematica or by numerical integration with Simpson's Rule and the computer routines for the zero and first order Bessel functions provided by Press et al [8].

Application

We have developed an independent studies project using Eq.12 in two and four dimensions, by providing a tabulated function of R as input for students. This function is the total correlation function, H(R), which is defined as,

$$H(R) = G(R) - 1 \qquad (13)$$

The pair correlation function, G(R), measures the order of a fluid at a particular number density, ρ. The Fourier Transform of H(R) is called the structure function, S(K). In this journal Harnett and Bishop [9], Lasky and Bishop [10] and Tiglias and Bishop [1] have described the behavior of G(R) for one, two and three dimensional systems respectively. Bishop, Whitlock and Klein [11] have computed G(R) for hard particle systems for a variety of dimensions and densities by Monte Carlo simulation methods. The Fourier Transform of H(R) has been evaluated by using Eq. 12 and employing Simpson's integration formula with a mesh size of $\Delta R = 0.01$ and a cutoff upper bound of $R = 4.0$. The numerical integration routines have been written in C and can perform the Fourier Transform of any tabulated data set. For this case the upper bound value in the integral in Eq. 12, only needs to be large enough so that G(R) has essentially become one and therefore, H(R) is zero.

Figure 1 presents the original G(R) Monte Carlo simulation data in two and four dimensions at $\rho = 0.70$. G(R) is zero when $R \leq 1.0$ since particles cannot penetrate each other. When G(R) attains a value of 1.0 the fluid is uniform in its structure. The appearance of the second and even small third peak in two dimensions indicates the onset of ordering at this density but in four dimensions there is essentially only a single peak. In four dimensions particles can easily avoid each other and therefore have a larger free space in which to move. Hence, higher densities are needed before particles start to become localized.

Figure 2 presents the Fourier Transform of the curves in figure 1. The behavior of the S(K) graphs at low values of K reflects the behavior of the pair correlation function at large R values. One needs to be in an R regime in which the pair correlation has decayed smoothly to a value of one and does not display oscillations. Otherwise, one obtains low K values of S(K) which are artifacts of the Fourier Transform

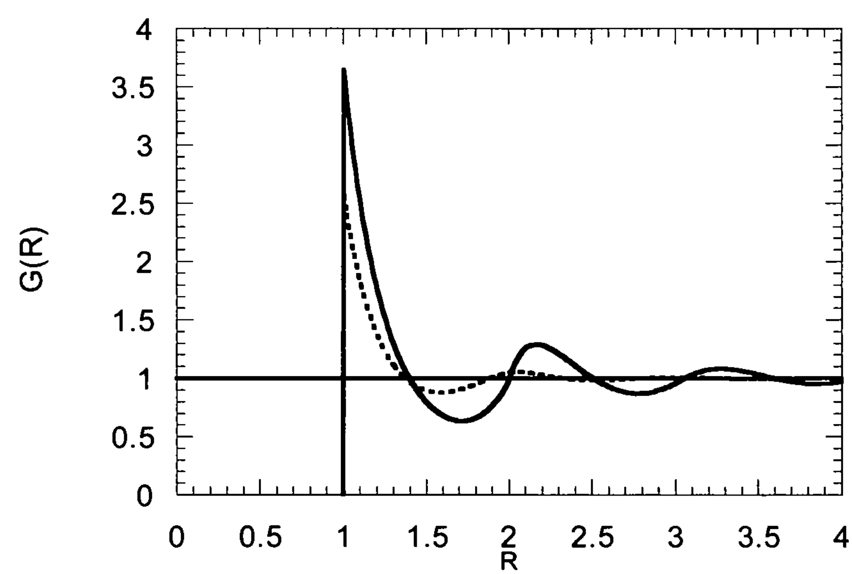


Figure 1: The pair correlation function for D=2 (solid line) and D=4 (dotted line) when $\rho = 0.7$.

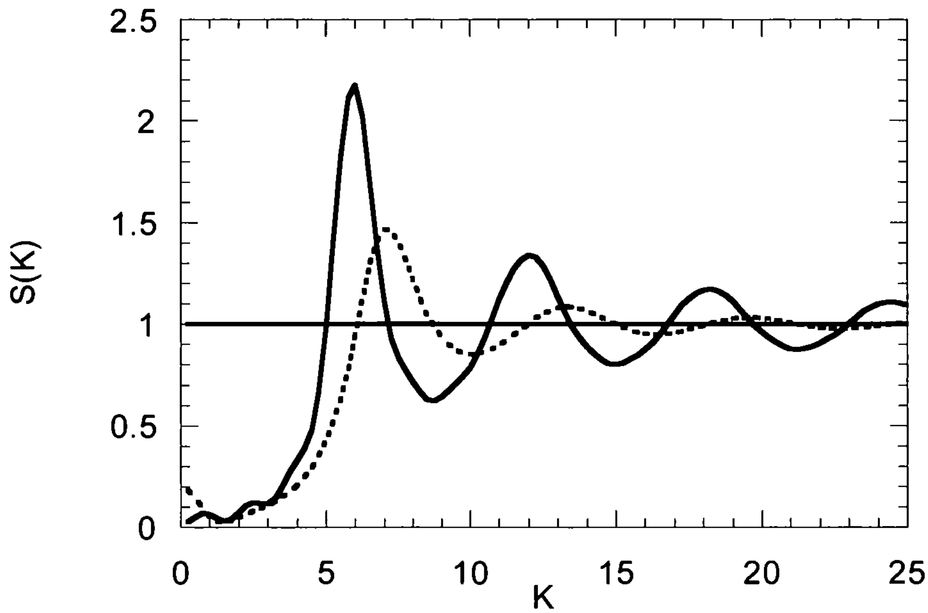


Figure 2: S(K) for D=2 (solid line) and D=4 (dotted line) when $\rho = 0.7$.

process. In Figure 2 the structure of G(R) is mirrored in S(K). The strong multiple peaks in S(K) for the two dimensional system confirms that it is much more ordered than the four dimensional one.

Conclusions

We have presented a general derivation and an interesting application of Fourier Transforms in arbitrary dimension by studying S(K) of hard particle systems in two and four dimensions. Having students numerically compute the Fourier Transform of tabulated data exposes them to important tools of analysis which will be of great use in their future careers.

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References

1. J.L. Tiglias and M. Bishop, "Fourier Transforms in One and Three Dimensions", Comp. Educ. J., XVIII, 47 (2008).

2. G. N. Watson, "A Treatise on the Theory of Bessel Functions", (Cambridge University Press, Cambridge, 1995).

3. M. Abramowitz and I. A. Stegun, "Handbook of Mathematical Functions", (Dover, New York, 1972).

4. A. Papoulis, "The Fourier Integral and Its Application", (McGraw Hill, New York, 1962).

5. R.N. Bracewell, "The Fourier Transform and its Applications", (McGraw Hill, New York, 2000).

6. I. N. Sneddon, "Fourier Transfoms", (Dover, New York, 1995).

7. N. V. Brilliantov and T. A. Poschel, "Kinetic Theory of Granualar Gases", (Oxford University Press, Oxford, 2004).

8. W.H. Press, S.A. Teukolsky, W.T. Vetterling and B.P. Flamery, "Numerical Recipes", (Cambridge University Press, New York, 1992).

9. J. Harnett and M. Bishop, "Monte Carlo Simulations of One Dimensional Hard Particle Systems", Comp. Edu. J., XVIII, 73 (2007).

10. M. Lasky and M. Bishop, "Monte Carlo Simulations of Two Dimensional Hard Particle Systems", Comp. Edu. J., XVIII, 42 (2008).

11. M. Bishop, P.A. Whitlock and D. Klein, "The Structure of Hyperspherical Fluids in Various Dimensions", J. Chem. Phys., 122, 074508 (2005).

Biographical Information

John L. Tiglias completed a B.S. in computer science at Manhattan College and is currently a graduate student in computer science at Stevens Institute of Technology.

Marvin Bishop is a Professor in the Department of Mathematics and Computer Science at Manhattan College. He received his Ph.D. from Columbia University, his M.S. from New York University and his B.S. from the City College of New York. His research interests include simulation and modeling and parallel processing.

GESTURE-BASED INTERACTIVE BEAM BENDING EXERCISES: AN INTERACTIVE AND INTUITIVE TOOL FOR STUDENTS

Tarek El Dokor, David Lanning, Justin Gigliotti
Embry-Riddle Aeronautical University
Prescott, AZ 86301

Abstract

Immersion and interactive experience are introduced into a Solid Mechanics beam bending lab exercise by utilizing gesture-based analysis that is inexpensive, utilizes off-the-shelf cameras, and is highly portable for ease of use in the classroom. A cantilever I-beam is rendered in virtual reality (VR) and a user's gestures are captured and interpreted in real-time to allow for natural interaction with the beam. Users can bend the I-beam with up to three degrees-of-freedom, via mechanics governed by well-known elastic beam theory. This approach evokes a more immersive feeling in students, the intended users of the application, keeping them more engaged in the exercise. A simple web camera captures hand motion and algorithms interpret various gestures in real-time. For instance, simply by moving their hand up/down or left/right, seeming to "grab" and push or pull the end of the beam, students can intuitively vary input parameter such as load or displacements to the free end of a cantilever beam. Feedback, such as axial stress distributions, is displayed in real time. This approach provides a supplementary tool that is much more current with the state of the art for learning tools and provides for the need to keep students engaged and interested in various exercises, while still delivering many of the pertinent concepts found in lecture-based engineering courses. Results are discussed from student engagement in supplementary exercises to a traditional sophomore-level undergraduate Solid Mechanics course. Future improvements to the current application are discussed.

Motivation

The Aerospace Engineering degree program at Embry-Riddle Aeronautical University is a comparatively standard four-year engineering program, much like engineering programs offered at numerous other universities throughout the United States. Much of the freshman year consists of courses in calculus, physics, and composition, the sophomore year includes courses in mechanics, the junior year provides depth in the particular engineering discipline, and much of the senior year revolves around the senior design project. While the Aerospace Engineering department has been active in increasing design and laboratory content throughout the curriculum, certain courses have changed little over the many years they have been taught. Solid Mechanics is one of these courses.

Solid Mechanics, typically taken during the second semester of the sophomore year by engineering students, has been taught to aspiring mechanical, civil, and aerospace engineers for numerous decades, and the course content has changed little over that period of time. Solid Mechanics may be considered the first course in engineering structures (perhaps this could be argued, depending on how one views the prerequisite course Statics), and involves computing the stresses and strains in rods, shafts, beams, columns, and other simple structures. One of the authors took such a class as an engineering student at a different university and used the wellknown text Mechanics of Materials by Gere and Timoshenko[1]. Now the author teaches the same class with the sixth edition of the same text[2].

A typical method for teaching Solid Mechanics and similar courses in mechanics is to spend some portion of the class time lecturing on theoretical principles, and the remaining time working problems on the board. Most student homework involves completing similar problems with pencil and paper, time and again sketching free-body diagrams and working with equations. Some instructors will take students into the laboratory once or twice during the semester and provide a quick demonstration of a tensile test or a beam bending experiment. The addition of a new undergraduate laboratory for the Aerospace Engineering program at Embry-Riddle has led to the addition of increased laboratory content in the solid mechanics course, including assignments based on strain gage data gathered by students, allowing for the comparison of experimental data with theoretical predictions in numerous instances. However, the implementation of such laboratories is difficult to accomplish on a weekly basis with multiple sections of 20-30 students each semester. Further, students often have difficulty visualizing stresses and strains in rigid structures, such as large beams loaded in the laboratory. An aluminum or steel beam under moderate loads will often deflect imperceptibly, perhaps leading to a lackluster demonstration.

The use of finite element (FE) theory, when supplemented with assignments that must be completed using a commercial FE computer program, such as NASTRAN or ANSYS, can begin to fill this gap. Students can create structures, load and constrain them, and then view the solutions. Color-coded stress distributions and plots of structural displacements greatly advance students' understanding of the effect of loading on structures and the subsequent possibilities for structural failure. However, sophomore students enrolled in solid mechanics are generally considered to be not far enough along in their education to be introduced to FE concepts and associated software. Due to a lack of widely-used visualization software, Solid Mechanics instructors typically resort to their frequently poor artistic skills to communicate such concepts to their students. Drawn on the board, the simple structures of beams, rods, shafts, and columns all look like rectangles, which is certainly uninspiring.

It is critical that the Solid Mechanics student fully understand the complete deformation behavior and stress distribution in the study of loaded structures. It is too easy for students to learn to simply view a set of equations as a 'black box' and to accept without question the answers that this produces. Students often experience a lack of context while solving such problems, and therefore can have little sense of whether or not an answer is correct. Appropriate visualization of both inputs and final results is critical to resolving this difficulty. Increased awareness on the part of the student of the problem at hand will lead to much-needed enthusiasm toward engineering during the sophomore year, which is key to larger issues such as student retention.

Laboratory Simulation for Education

There exists a vast array of computer simulation directed towards education, and the broad field of engineering is no exception. In an effort to reduce the need for costly laboratories desired for hands-on student engineering instruction, many educators are focusing attention on developing supplementary computer exercises, referred to by some as "virtual instruments."[3] These efforts are seen as particularly important as an increasing number of distance-learning degree programs are established.[4-6] There has also occurred some of the necessary comparison in student learning outcomes between real and simulated laboratory environments,7 although it appears that a thorough evaluation remains incomplete.

Educational simulations that incorporate virtual reality (VR) strive to increase realism and to immerse the user in an interactive environment. One of the many educational goals is to increase participation in active learning, and thus increase retention of key learning concepts. Many educators are creating such simulations and exploring the impacts on student learning outcomes.[8-12] The use of display devices worn on the head and instrumented gloves to provide tactile feedback can greatly enhance the immersion and interaction of the user within the simulated environment. Some of the workers in the cited references are uncovering benefits to learning outcomes, but such costly equipment can limit the usefulness when serving large numbers of students. The computer vision application described in this work offers many of the same benefits from VR, but without much of the costly equipment that has so far been associated with the term.

Computer Vision and Gesture Recognition

Computer vision is a technology that enables computers to perceive the world around them[13]. This is accomplished by analysis of images or other multidimensional data to come to conclusion regarding distribution patterns in such images. Computer vision applications span a plethora of fields, from medical imaging, to surveillance, to human-computer interfaces through gesture recognition. Gesture recognition is a discipline of computer vision in which users' gestures are interpreted via spatial pattern distributions using various mathematical algorithms. Gestures, as spatial data information, are usually grabbed via cameras or other remote sensing devices. This information is then relayed to a computer in which various algorithms are utilized to interpret the data within a given context, to identify one of a number of intended gestures. Gesture recognition involves machine training on a predefined data set, and is usually accomplished in real-time, enabling a new generation of human-computer interactivity that precludes a mouse, keyboard, or any other peripheral mechanical device, which results in a more natural medium of interactivity[14]. Such a more natural, ergonomic approach makes applications much more immersive, and thus easier to accept for users. This is advantageous for educational implementations, since student engagement and retention is very important. Immersion of students into fundamental physical concepts by allowing manipulation of various parameters via the technologies of computer vision and gesture recognition gives educators a clear advantage in concept delivering.

Implementation

El Doker and Lanning, faculty in the departments of Electrical Engineering and Aerospace Engineering, respectively, came together to pursue projects in undergraduate education. El Doker, with a specialty in computer vision, proposed the creation of a series of computer laboratory exercises to enable student to visualize and manipulate an object or series of objects that otherwise may not be easily done in a typical lecture or laboratory setting. It was decided that Solid Mechanics would be an appropriate course for which a set of exercises could be created. Students enrolled in this course often do not fully grasp concepts of stress distribution and deformation patterns. The manipulation of computer-generated images of engineering structures, with displacements and stress distributions displayed in real-time, with certain displacements appropriately exaggerated, could lead to quicker mastery of essential concepts. Justin Gigliotti is an electrical engineering student previously working on other computer vision projects, and was chosen to implement the programming. It is noteworthy that he has no background in solid mechanics, but nevertheless completed the initial simulation admirably.

Beam bending

The first simulation was a cantilever beam bending exercise with transverse point loads at the free end. This is a basic configuration used in countless solid mechanics problems, and while students have a reasonably clear understanding of the displacements, the overall stress distribution is often underappreciated. The cantilever beam is loaded at the free end, with point loads possible in both primary directions perpendicular to the beam axis (side to side and vertical). These point loads in the y and z-directions, resulting in unsymmetric bending, gives a stress distribution that the solid mechanics student may not encounter until a later class in structures. Students should catch on to the additional concepts quickly after completing the demonstration, however.

Bending stresses in linear elastic unsymmetric beams, as taught in most undergraduate structures courses, follow the general equation:

$$\sigma_x = \frac{I_z M_y + I_{yz} M_z}{I_y I_z - I_{yz}^2} z - \frac{I_y M_z + I_{yz} M_y}{I_y I_z - I_{yz}^2} y$$

Eq. 1

where the x-direction is along the axis of the beam, σx is the bending stress, Iy and Iz are second area moments of inertia, Iyz is the product of inertia, My and Mz are the bending moments, and y and z are coordinates with respect to the cross-section centroid. The coordinates are shown in Figure 1.

In the present version of the exercise, the problem was simplified by the use of a symmetric cross-section, and since Iyz therefore goes to zero, the bending stress equation simplifies to:

$$\sigma_x = \frac{M_y}{I_y} z - \frac{M_z}{I_z} y$$

Eq. 2

This is often referred to as unsymmetric loading of a beam with a symmetric cross-section. As the beam is loaded, the deformed beam is displayed following the well-known transverse displacement equations for an end-loaded cantilever beam:

$$v = -\frac{P_y x^2}{3EI}(3L - x)$$

Eq. 3

$$w = -\frac{P_z x^2}{3EI}(3L - x)$$

Eq. 4

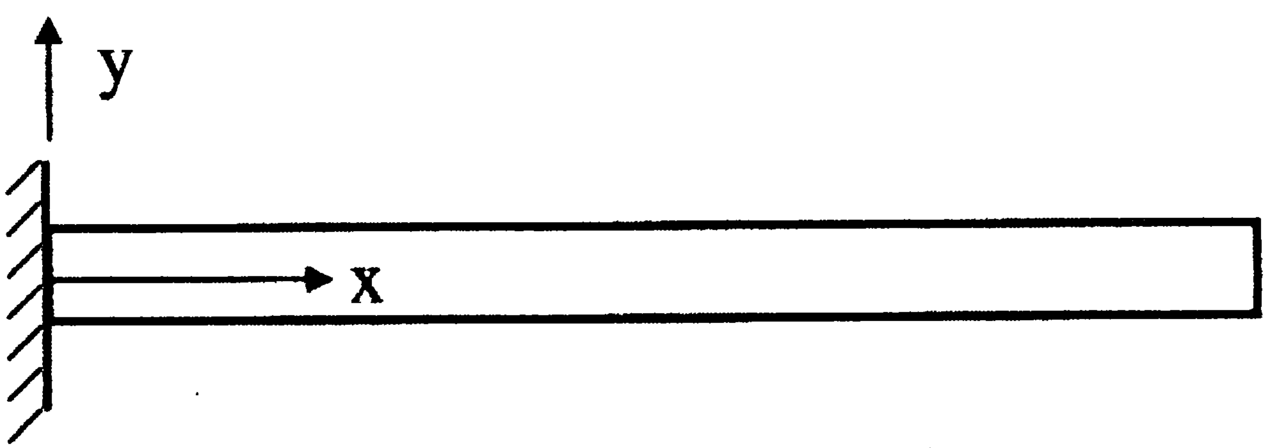

Figure 1: Coordinate system for a cantilever beam.

where Py and Pz are point loads that are considered positive if they are in the negative y- and negative z-directions, respectively, L is the length of the beam, x is the coordinate along the axis of the beam, and E is the elastic modulus. The displacements v and w are in the y and $z$directions, respectively.

Computer vision implementation

There are three main subsystems to this pplication: i) The vision control system, ii) the rendering system, and iii) the user interface:

i) The vision control system: The real-time computer vision system is made up a twodegree of freedom controller. Image frames are captured in real-time from a camera, with a user in the camera's field of view. The user then clicks in the region of motion (the user's hand), and an optical tracking algorithm13 is then utilized to track the hand motion. The beam is then controlled and manipulated as the hand moves left/right and up/down. Figure 2 shows a user interacting with the simulation while sitting in front of a laptop with a simple web camera. Figure 3 illustrates the overall block diagram of the system.

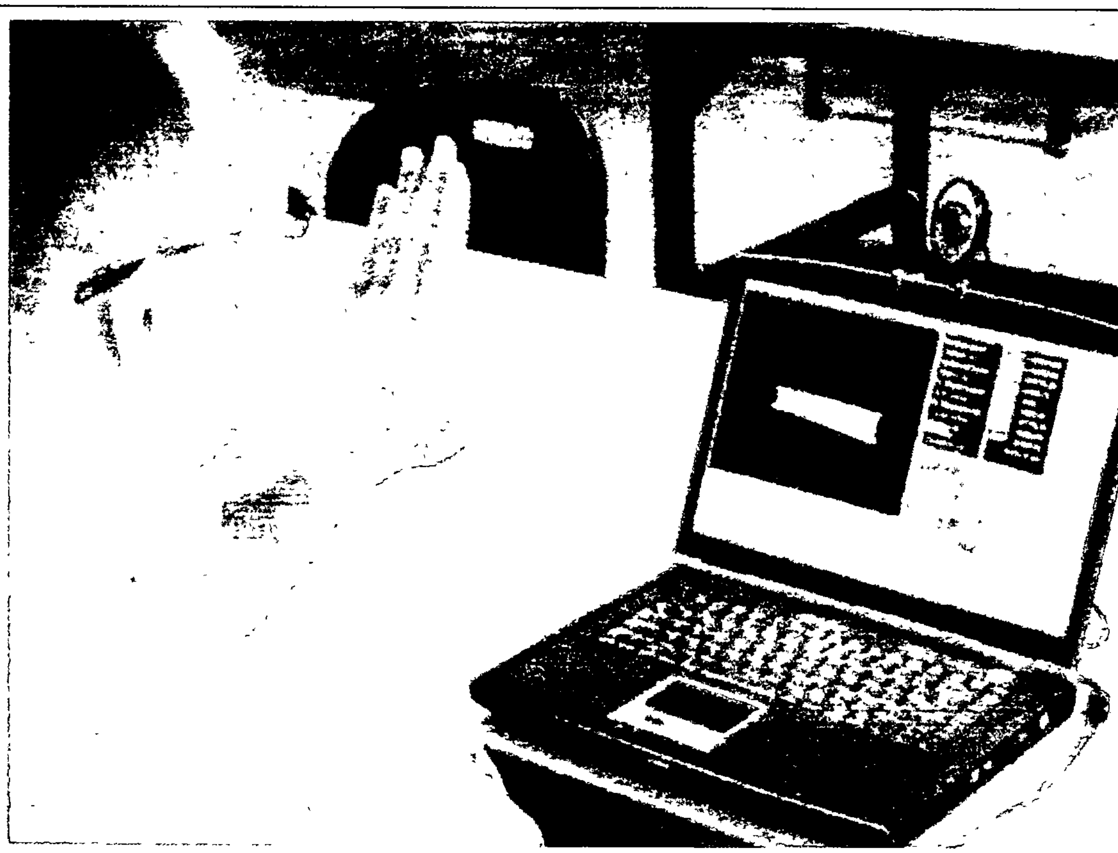

Figure 2: User running the beam-bending simulation.

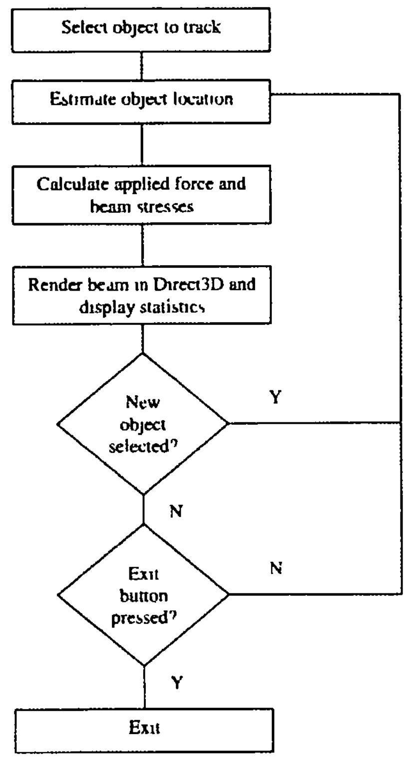

Figure 3: Flow chart of beam bending algorithm implementation.

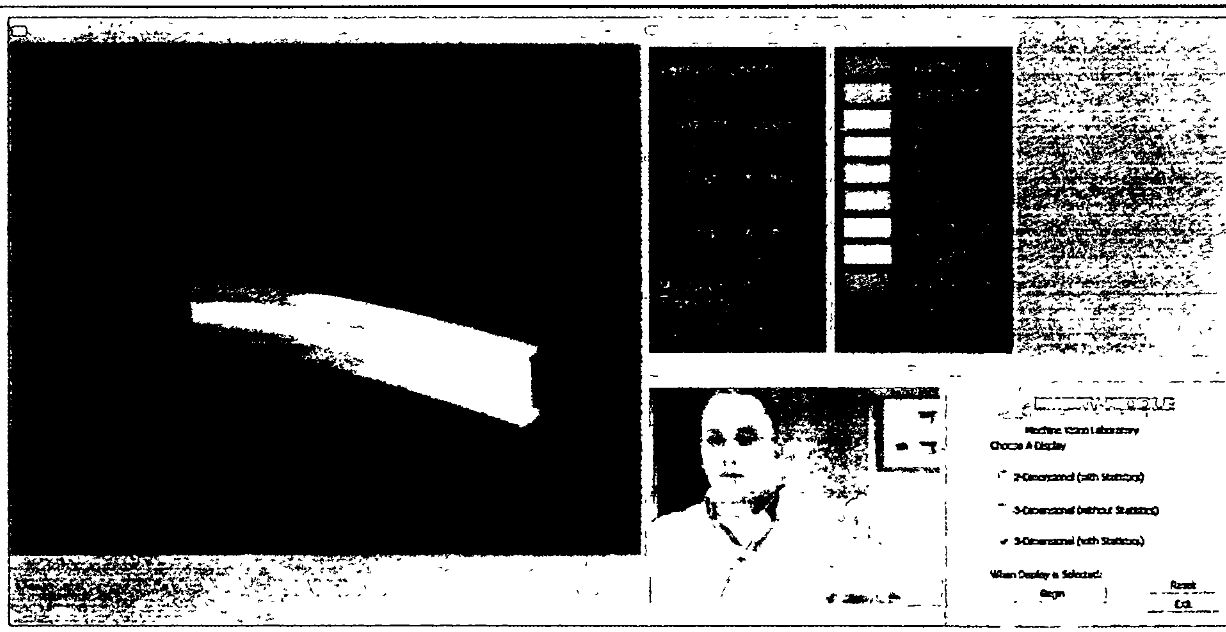

Figure 4: Graphical interface of the beam-bending simulation.

ii) The rendering system: openGL is utilized to render the I-beam using point sprites, and a transformation function given by the beam equations present in Eqs. 1-4. Multithreading is utilized to enhance the system's performance, such that the vision and rendering are each processed on separate threads.

iii) The graphical user interface, shown in Figure 4, is comprised of a series of input fields in which various parameters are manipulated. The user inputs vertical and horizontal load by moving the hand in those respective directions. The magnitude is controlled by the extent of the motion in the corresponding direction. The stresses are color-coded in a fashion typical of FE software, blue for compressive stresses grading to red for high tensile stresses. Currently, the colors are coded to absolute values of stresses, so that as the magnitude of the load is increased, the stress distributions are seen to develop from low magnitudes to high magnitudes.

Laboratory in the Classroom

A small section (8 students) of Solid Mechanics was chosen for the introduction of the beambending simulation in the autumn semester of 2006. The programming was completed towards the end of the semester, and unfortunately the classroom exercise was conducted with only two weeks before the end of the semester. This was quite some time after beam stresses were introduced in the course, which typically occurs during week six or seven. A single laptop with camera was brought into the classroom for the demonstration.

The instructor introduced the exercise, including the concept of color-coded stress distributions over the surface of a simple structure, and asked the students to describe what they would expect to see for basic loading conditions. The idea of unsymmetric bending (bending components mutually perpendicular to the loading axis and each other) was discussed, and again students were asked to speculate on the resulting stress distributions for various loading combinations. The students then sat down individually at the laptop/camera workstation and manipulated the beam through hand movements to see if their assumptions were correct. The laptop display was also projected by the overhead projector onto a screen for the rest of the class to observe. Afterwards, the instructor led a discussion to determine the reactions of the students to the exercise.

First, the students were interested in and intrigued by the new technology itself. While the use of technology solely for entertainment is certainly of limited value in the classroom, it can focus immediate interest in the exercise. The use of gestures to interact with the simulation appeared to keep students involved for the duration of the exercise. Perhaps more importantly, the use of gestures to control both the magnitude and direction of the force on the cantilever beam created a situation where the student could quickly and easily change input parameters.

Students appeared to respond favorably to a simulation environment in which abstract concepts were graphically realized on the computer screen, and manipulation of the object of interest was exceedingly easy. While all students understood that the highest stresses would be at the root of the cantilever beam, and it was acknowledged that this was a fairly simple loading case, they were interested in a tool that could be used for more complex loads and support conditions, where the user could easily modify the conditions of the problem and view the results in real time. Several students were interested in extending the exercises to problems in which they had particular difficulties understanding the relationship between loads and supports, such as solutions to indeterminate structures and the application of superposition for complex loadings.

The feedback was informal and qualitative, but critical to developing a plan for the subsequent semester (spring of 2007), in which additional features would be incorporated into the classroom tool. The instructor believed that students quickly developed an appreciation of concepts that were discussed minimally during lecture (unsymmetric bending) and an improved understanding of overall patterns of stress distributions. Students generally found that utilizing natural interaction via gestures to be intuitive and interesting. Currently, a plan for improved evaluation of student learning is being put together for the following semester. Several changes to the content of Solid Mechanics have been implemented in the past academic year, and the plan is to broadly identify whether or not ABET student learning outcomes are being positively or negatively impacted by these content changes, including the evolving beam simulation exercises.

Continued Development

Obviously, there are endless variations of problems that could be implemented using this gesture-based interactive tool for students, for Solid Mechanics as well as other courses. The challenge is to ensure that the development of this tool leads to improved student achievement. This preliminary classroom introduction served primarily to gauge students' reactions to the use of this technology for visualizing a particular problem, demonstrating the ease of use of such an interface and attempting to help students understand stress distributions of a cantilever beam.

In the next several months, the simulation will be expanded to include the effect of axial loads on the bending stress distributions, and perhaps torsional loads as well. The authors hope to expand options for user inputs on beam geometry and material properties. More importantly, a set of problems and questions will be constructed to accompany each computer exercise to be completed by the students. This will be used to create a more complete classroom exercise in which learning outcomes can be quantitatively evaluated. Student understanding of displacements and stress distributions must be evaluated before and after the use of the gesturebased simulation exercise. Finally, this must be designed so that it can be implemented easily with multiple sections of 20-30 students each semester.

Summary

A solid mechanics demonstration of beam bending has been paired with a computer vision tool allowing students to quickly develop a broader understanding of concepts of stress distributions and structural displacements. This new simulation environment has been developed to be easily implemented in a classroom environment, which allows for learning of concepts not easily grasped in a traditional lecture setting.

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Bibliography

1. Gere, J. and Timoshenko, S. Mechanics of Materials, Second Edition. Boston, MA: PWS Publishers, 1984

2. Gere, J. Mechanics of Materials, Sixth Edition. Belmont, CA: Thomson, 2004.

3. Mosterman, P.J., Dorlandt, M., Campbell, J.O., Burow, C., Bouw, R., Brodersen, A.J., and Bourne, J.R. "Virtual Engineering Laboratories: Design and Experiments," *Journal of Engineering Education*, July 1994, pp. 279-285.

4. Feisel, L.D. and Rosa, A.J. "The Role of the Laboratory in Undergraduate Engineering Education," *Journal of Engineering Education*, January 2005, pp. 121-130.

5. Gillet, D., Latchman, H.A., Salzmann, C., and Crisalle, O.D. "Hands-On Laboratory Experiments in Flexible and Distance Learning," *Journal of Engineering Education*, April 2001, pp. 187-191.

6. Hashemi, J., Chandrashekar, N., and Anderson, E.E. "Design and Development of an Interactive Wed-based Environment for Measurement of Hardness in Metals: a Distance Learning Tool," *International Journal of Engineering Education*, Vol. 22, No. 5, 2006, pp. 993-1002.

7. Wiesner, T.F. and Lan, W. "Comparison of Student Learning in Physical and Simulated Unit Operations Experiments," *Journal of Engineering Education*, July 2004, pp. 195-204.

8. Bell, J.T. and Fogler, H.S. "Recent Developments in Virtual Reality Based Education," ASEE Annual Conference Proceedings, Washington DC, 1996.

9. Bell, J.T. and Fogler, H.S. "Ten Steps to Developing Virtual Reality Applications for Engineering Education," ASEE Annual Conference Proceedings, Milwaukee WI, 1997.

10. Ross, W.A. and Aukstakalnis, S. "Virtual Reality: Potential for Research in Engineering Education," *Journal of Engineering Education*, Juty 1994, pp. 287-291.

11. Impelluso, T. and Metoyer-Guidry, T. "Virtual Reality and Learning by Design: Tools for Integrating Mechanical Engineering Concepts," *Journal of Engineering Education*, October 2001, pp. 527-534.

12. Whitman, L., Malzahn, D., Madhavan, V., Weheba, G., and Krishnan, K. "Virtual Reality Case Study throughout the Curriculum to Address Competency Gaps," *International Journal of Engineering Education*, Vol. 20, No. 5, 2004, pp. 690-702.

13. Forsyth, D. and Ponce, Jean Computer Vision: A Modern Approach, Prentice Hall 2002.

14. Dix, A., Finlay J., Abowd, G., and Beale, R. Human-Computer Interaction, Second Edition, Prentice Hall, 1998.

Biographical Information

Tarek El Dokor is an Assistant Professor of Electrical Engineering at Embry-Riddle Aeronautical University in Prescott, Arizona.

David Lanning is an Assistant Professor of Aerospace Engineering at Embry-Riddle Aeronautical University in Prescott, Arizona.

Justin Gigliotti is an undergraduate student in Electrical Engineering at Embry-Riddle Aeronautical University in Prescott, Arizona.

Computers In Education Division

The Computers in Education Division (CoED) invites papers for the 2010 ASEE Annual Conference. CoED provides a broadly-based forum for exchanging ideas on all areas that involve computers and computational tools for education in engineering and technology. The division is known for its diverse participation from all disciplines represented by ASEE. The CoED program committee encourages submission of papers in any such computer-related topic area. As an example, recent educational topics areas have included instrumentation and laboratory systems, digital signal processing (DSP) educational tools, mobile robots, impacts on engineering and computer science education, mobile computing (PDA, laptop, tablet PC, etc.) applications and ramifications in education, embedded computing (including microprocessor and microcontroller selection and applications), hardware descriptive language (HDL) education innovation, software packages (including symbolic computing and equation solvers), simulation and animation, computer architecture, computing tools used in outreach programs, and internet applications in classroom and lab. Outstanding papers will be considered for a division best paper award, and may also be considered for the CoED peer-reviewed journal. To present at the conference, you must have your full paper accepted by the conference peer reviewers. Persons interested in proposing a workshop on a topic related to CoED should contact the Program Chair for information. If you have any questions, please contact the 2010 CoED Program Chair: Cameron Wright, Ph.D., P.E., at e-mail: chgwfajuwyo. edu.

COMPUTERS IN EDUCATION DIVISION (CoED) of ASEE

The Computers in Education Division (CoED) of ASEE currently has two main avenues of endeavor: the Computers in Education Journal and the CoED sessions at the ASEE Annual Conference. Both of these avenues of service to CoED members and to the profession are dependent upon volunteer effort.

The Computers in Education Journal is a peer-reviewed publication. All papers submitted are reviewed in detail by senior faculty volunteers before acceptance for publication. Volunteers perform the editorial functions and the final proof-reading after authors have proof-read the galleys of their papers. The Computers in Education Journal is financially self-supporting through page charges by authors, subscriptions by organizations/libraries/individuals, and the $7.00 annual CoED membership dues through ASEE. The Computers in Education Journal is published quarterly.

The CoED sessions at the ASEE Annual Conference are organized by the CoED Program Chairman with emphasis in topical areas of interest to CoED members. The effort is volunteer from start to finish and the CoED sessions are advertised and promoted by CoED and by ASEE in its Annual Conference publications and mailings.

The Computers in Education Journal papers once were totally from papers presented at the CoED sessions of the ASEE Annual Conference. That source of Computers in Education Journal papers is now about one-fourth of the total papers published, but all papers presented in CoED sessions of the ASEE Annual Conference are considered as pro forma submissions to the Computers in Education Journal and go through the peer review process.

CoED members who volunteer services to the profession through CoED endeavers appreciate support and encouragement as they strive to make the CoED endeavers enhance the professional life of educators.

Computers in Education Journal
On-Line

The Journal can be reached at http://www.asee.org/about/publications/divisions/coed.cfm or by going to the ASEE web site at www.asee.org, selecting the Publications/Division Publications tab. This area includes a list of CoED Officers and Directors, information for authors, and full text of the Journal. Detailed information for authors can be found at http://www.asee.org/publications/divisions/ upload/CoEd-Detailed-Information-for-Authors.pdf.

Full text of the Computers in Education Journal is available on line to CoED members only, made accessible by your ASEE Member Number. Many articles contain color illustrations that cannot be appreciated in the print version of the Journal.