Controls Curriculum Survey
A CSS Outreach Task Force Report

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1 Background

In early 2008, the IEEE Control Systems Society approved an outreach initiative addressing two topics: (1.) Developing internet content in systems and control to promote the field and (2.) facilitating better connections between academia and industry. With respect to item (2.), a project was proposed to conduct a broad-based survey of how control is taught for undergraduate and masters degrees, solicit comments from industry and academia on capabilities and perceived shortcomings of entry-level control engineers, and initiate discussion on how curricula might be improved. The project was approved by the CSS Board of Governors in December 2008; a survey was developed, and data collected between 28 April and 15 August 2009. In all, a total of 225 CSS members (about 3.2% of worldwide membership) responded to at least some of the survey questions.

Many people contributed to the development of the survey and provided valuable advice and insightful comments. In particular:

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The IEEE Control Systems Society has not officially endorsed any conclusions or recommendations contained in this report.

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2 Executive Summary

The Executive Committee of the IEEE Control Systems Society distributed the following invitation to all CSS members in late April and mid-August, 2009:

> **A note from the Executive Committee of the IEEE Control Systems Society**
>
> 28 April, 2009
>
> Dear fellow CSS members:
>
> ... the IEEE Control Systems Society (CSS) Task Force on Outreach has developed an informal survey with the objective of evaluating capabilities and perceived shortcomings of entry level control engineers in industrial positions. Our goals are to collect insights and recommendations from academic and industry experts and to establish a database of links to public web pages for controls courses that may be used as a resource for educators and practitioners. The survey will require a few minutes of your time.
>
> We invite and encourage all members to take the survey, which may be accessed at `http://www.surveygizmo.com/s/114514/outreach-survey-on-control-education-version-03.`
>
> Leaders and members of the Task Force will manage the data. The survey results will be published in aggregated form on the CSS website, `http://www.ieeecss.org/.`

No representation is made that the survey was in any way scientific: All CSS members were solicited via email, and no effort was made to assure the selection of a representative sample. The survey, hosted by surveygizmo.com, consisted of a few introductory demographic questions presented to all respondents. Industry, university faculty and student respondents were then directed to distinct questionnaires. The survey began with two general questions regarding the capability and quality of entry-level control engineers in industry: "What is your overall opinion of the capability of entry-level control engineers graduating in your discipline/hired by your organization?" and, "what areas (if any) need to be strengthened or added to the curriculum to better prepare control engineers for industry?" Industry respondents were then presented with lists of specific systems and control methods, tools and techniques and asked to rate each on a scale from "not required" to "essential." University faculty respondents were presented with the same list and asked which, "would be expected of entry level control engineers graduating from your institution?" The entire survey is reproduced in the appendix.

The good news is that, in general, there is substantial agreement between industry and academia on most of the surveyed topics. That is, the practicing engineers who responded to this survey typically feel that universities are teaching the right material, and that graduates are generally well prepared for industry positions. Industry and university respondents agree that there should be increased emphasis on "hands-on experience" and "industry focused" design in controls curricula. Highlights:

- Eighty percent of industry respondents rate the capability of new graduates to be "good" or "fair" (about 73% of industry respondents with hiring authority rate graduates "good" or "fair"). Almost 85% of university faculty put new graduates in these categories. On the other hand, only 32% of industry respondents rate new graduates "good to excellent," whereas 50% of university faculty respondents rate graduates that way, an indication that faculty overrate the quality of graduating students in terms of satisfying industry needs.
- Seventy-two percent of industry respondents think "hands-on experience" is the area that most needs to be strengthened to better prepare control engineers; About 61% of university faculty respondents agree (80.6% of non-EE/CE faculty). This is further reflected in industry emphasis on the importance of "noncore" subjects such as real-time operating systems, real-time software techniques and system integration.

- A significant majority of industry respondents consider mathematical modeling of physical systems to be a valuable skill. Models and methods considered to be "important" or "essential" include control-oriented models, simulation models for system verification or product design, nonlinear models, real-time models for hardware-in-the-loop verification and experimental system identification methods. Significantly, only linear models and control-oriented models were identified by more than 50% of university respondents as "topics covered in a course or courses that you regularly or occasionally teach, and that would typically be completed by entry level control engineers graduating from your institution."
- Classical control design techniques identified by industry respondents include PID tuning and integrator windup (considered "important" or "essential" by 92.8% and 83.6% of industry respondents, respectively); 69.1% and 36.1% of faculty respondents identified these topics as part of a curriculum for entry level control engineers. Robust control design (H_∞, μ analysis) is considered among the least important of control topics by industry respondents, yet some of these topics are well covered in academic curricula according to faculty respondents. In contrast, survey data suggest that model predictive control (MPC) is an area of interest for industry that is not typically covered in a curriculum aimed at entry-level engineers.
- More than 50% of industry respondents consider the following implementation issues to be "important" or "essential": Characteristics of sensors and actuators (84.9%), numerical methods for real-time integration (55.8%), real-time software techniques (69.2%) and real-time operating systems (50.9%). Of these topics, only "characteristics of sensors and actuators" was identified by more than 50% of university faculty respondents as being part of an entry level control curriculum.

Detailed statistics on survey respondent demographics and survey responses are included in the rest of this report. Several pages of verbatim comments from respondents are also included in the appendices.

3 Demographics

As noted above, the survey was not intended to be scientific. With the exception of "Where do you work?" all survey questions were optional, so sample size and university/industry distribution are different for different questions. Altogether, there were 225 unique survey responses; that is, respondents who answered some or all of the survey questions. Of these respondents, 75 were from industry or government, 131 were university faculty and 19 identified themselves as students.

Industry respondents were asked, "Typically, what is the academic background of entry level controls engineers hired by your organization (select as many as required)?" University faculty and student respondents were asked, "What is your academic department?" Not surprisingly, the majority of university faculty who chose to respond to this question represented Electrical or Electrical and Computer Engineering Departments (65%), corresponding to the majority of new hires identified by industry respondents (89.2%). Mechanical engineers represented the next largest number of new hires and faculty respondents at about 43% and 14% respectively (see Table 1). The majority of respondents consider "entry level" engineers to have obtained a US bachelors or masters degree or equivalent thereof (4 to 5 years of study, Table 2).

Geographically, respondents correspond roughly to Control System Society demographics. Of the respondents who chose to identify their country, 46.5% were from the United States. This compares to 45.2% of the CSS membership from the US. Other represented countries are approximately aligned with the CSS: Italy is slightly over represented in the survey; Great Britain slightly under represented, see Tables 3 and 4. The Control Systems Society does not have statistics on industry versus university representation.

Industry respondents were not required to enter their affiliation, but 28 chose to do so. A wide range of industries are represented in the survey including automotive (Ford, General Motors and Toyota),

Table 1: Who Took the Survey?

Academic Background of New Hires Industry Respondents (65 Responses [a])		Academic Department Faculty Respondents (117 Responses)		Academic Department Student Respondents (17 Responses)	
Electrical/Electrical and Computer	89.2%	Electrical/Electrical and Computer	65.0%	Electrical/Electrical and Computer	82.4%
Mechanical	43.1%	Mechanical	13.7%	Mechanical	5.9%
Aerospace	18.5%	Aerospace	3.4%	Mechatronics	5.9%
Industrial	13.9%	Chemical	2.6%	Robotics	5.9%
Chemical	10.8%	Other	15.3%		
Civil	6.2%				
Other	10.5%				

[a]Multiple responses permitted; totals may not sum to 100%

Table 2: "Entry Level Engineer"

Years of Study (113 Respondents)	
4 years	52.2%
5 years	23.9%
3 years	17.7%
6 years	3.5%
More than 6 years	2.7%

aerospace/defense (Boeing, L-3 Communications, Lockheed-Martin, United Technologies), electronics, software and process industries. No industry seemed overweighted in the sample.

4 Survey Results

4.1 Overall Opinion of entry-level Control Engineers

University faculty and students were asked to respond to the question, 'What is your overall opinion of the capability of entry-level control engineers graduating in your discipline?" Industry respondents were asked, "What is your overall opinion of the capability of typical entry-level control engineers hired by your organization?" All respondents were given the following definitions:

EXCELLENT: Solid understanding of systems and control fundamentals and facility with typical industry modeling, analysis and implementation tools; capable of working independently to model and analyze real-world industrial systems, and develop and implement control solutions. Can make immediate individual contributions to the enterprise.

GOOD: Solid understanding of systems and control fundamentals and acquaintance/familiarity with some modeling, analysis and implementation tools; capable of working with a mentor or with modest supervision to model and analyze real-world industrial systems, and develop and implement control solutions. Can rapidly make contributions with experienced engineers as part of a team.

Table 3: Respondents' Country

Industry		University	
United States of America	44	United States of America	43
Canada	4	Italy	12
Germany	3	Colombia	6
Italy	2	Canada	5
United Kingdom of Great Britain	2	China	5
Other[a]	12	Germany	4
		Malaysia	3
		Pakistan	3
		Spain	3
		Turkey	3
		France	2
		India	2
		Iran	2
		Romania	2
		Other[b]	25
Total Responses:	67	Total Responses:	120

[a]One each: Australia, Brazil, Denmark, India, Japan, Kuwait, Mexico, Pakistan, Saudi Arabia, Sri Lanka, Sweden, Switzerland

[b]One each: Argentina, Australia, Belgium, Bosnia, Brazil, Czech Republic, Egypt, Estonia, Greece, Indonesia, Ireland, Israel, Lesotho, Malta, Mexico, New Zealand, Poland, Portugal, Singapore, Slovenia, Sweden, Switzerland, Thailand, Trinidad Tunisia, United Kingdom of Great Britain

Table 4: Survey and CSS Demographics (University Faculty and Industry Respondents)

Country	Survey Respondents	CSS Membership
United States of America	46.5%	45.2%
Italy	7.5%	3.0%
Canada	4.8%	4.8%
Germany	3.7%	2.4%
China	2.7%	1.6%
Great Britain	1.6%	2.6%
Other	33.2%	40.4%

Table 5: Represented Industries

Company or Industry
A.I. Solutions, Inc.
Aramco Services Company
ATCO Power Ltd
Boeing
Corning Inc. (2)
Danieli Automation SpA (2)
Ericsson AB
Evan's and Sutherland
General Motors Research & Development
Goodrich Corp.
Hitachi
HYDRO-QUEBEC
L-3 Communications (2)
Lockheed Martin
Mathworks
Ford Motor Company (2)
PsiL GmbH
SABIC (Saudi Basic Industries Corporation)
Scitor Corp.
Self-employed
SNC-Lavalin, Inc.
Toyota Technical Center
United Technologies Research Center
Westinghouse Electric Company

FAIR: Understands systems and control fundamental concepts, but requires substantial additional training to model and analyze real-world industrial systems or implement solutions; can carry out tasks under the direction of an experienced engineer as part of a team.

POOR: Does not have a good grasp of systems and control fundamentals, or is deficient in an important skill such as mathematics; requires substantial additional training before technical contributions to a team or project may be expected; requires explicit direction and supervision.

Most respondents, both industry and university faculty, consider new hire control engineers to be fair to good (Table 6), although a substantially larger percentage of responding faculty consider graduates to be "good" (43.6%) than do practicing engineers in industry or government (27.7%). There was not a noticeably significant difference of opinion between all industry respondents and those with hiring authority, nor between EE/CE faculty and other disciplines. Of the 17 students who responded to this question (this was the only question presented to students), 8 considered their capability to be "fair," 5 "good" and 2 "poor" (the other two had no opinion).

Table 6: Perceived Capability of Entry Level Control Engineers

	Industry		**University**		
	All Industry (65 Responses)	Hiring Authority (37 Responses)	All Faculty (117 Responses)	EE/CE (75 Responses)	Non-EE/CE (42 Responses)
Excellent	4.6%	8.1%	6.0%	6.7%	4.8%
Good	27.7%	21.6%	43.6%	44.0%	42.9%
Fair	52.3%	51.3%	41.0%	40.0%	42.9%
Poor	12.3%	13.5%	6.8%	8.0%	4.8%
No opinion	3.1%	5.4%	2.6%	1.3%	4.8%

4.2 What Areas Need to be Strengthened?

Sixty-four industry engineers and 109 university faculty responded to the question, "What Areas Need to be Strengthened to Better Prepare Control Engineers?" Respondents were given the following choices (more than one choice was allowed):

BASIC METHODS: Classical and modern control methods and math courses typically expected of all undergraduate engineering students such as analytic geometry, calculus and elementary differential equations.

ADVANCED METHODS: Mathematics beyond what may be typically expected of all undergraduate engineering students (vector algebra, partial differentiation; line, surface, and volume integrals; linear algebra) and advanced control methods (Liapunov stability methods, adaptive and robust control).

INDUSTRY-FOCUSED DESIGN: Instruction in specific sofware packages such as MAPLE^{TM}, Mathematica^{TM}, MATLAB/Simulink^{TM}or other modeling and analysis tools widely applied in industry; basic control actions and industrial automation.

MATHEMATICAL MODELING OF DYNAMICAL SYSTEMS: Linear and nonlinear modeling for simulation, system identification, linearization and model reduction.

HANDS-ON EXPERIENCE: Laboratory implementation of controls using high-level (rapid prototyping) systems and academic hardware (inverted pendulum, Lego Mindstorms^{TM}, etc.).

COMPUTER HARDWARE AND SOFTWARE: Embedded microprocessor architecture, real-time sofware development, automatic code generation and other embedded implementation issues.

By far, "Hands-on Experience" was considered by industry and university respondents (both EE/CE and non-EE/CE faculty) to be the area most in need of strengthening, followed by "Industry-focused Design," "Computer Hardware and Software," and "Mathematical Modeling of Dynamic Systems." Half of the 36 non-EE/CE faculty respondents thought "Basic Methods" required strengthening (Table 7).

Table 7: What Areas Need to be Strengthened to Better Prepare Control Engineers?

Multiple responses permitted; totals may not sum to 100%

	Industry	**University**		
	(64 Respondents)	All Faculty (109 Respondents)	EE/CE Faculty (73 Respondents)	Non-EE/CE Faculty (36 Respondents)
Hands-on Experience	71.9%	60.6%	50.7%	80.6%
Industry-focused Design	48.4%	49.5%	46.6%	55.6%
Computer Hardware and Software	46.9%	39.5%	35.6%	47.2%
Mathematical Modeling of Dynamic Systems	45.3%	45.0%	46.6%	41.7%
Advanced Methods	28.1%	34.9%	34.3%	36.1%
Basic Methods	28.1%	34.9%	27.4%	50.0%
Other [a]	20.3%	11.0%	22.2%	

[a]Other areas identified by at least one **industry** respondent include: Statistical analysis, marketing and finance, communications skills, basic understanding of industrial sensors, PID control and software design. Other areas identified by at least one **faculty** respondent include: Basic physics and chemistry, basic economics and management, fault detection and diagnosis, interdisciplinary and humanities, and optimization.

4.3 Topics Included in a Controls Curriculum

Tables 8 through 18 refer to questions in which lists of topics, methods or tools were presented to respondents. Industry respondents were asked to rate the topics on a scale from "Not Required" to "Essential." University faculty were asked if the topics were part of the controls curriculum. Each table below contains the industry ranking, university response and number of respondents which, in some cases, was small.

Table 8: Mathematical Review and Basic Concepts

	Industry Ranking (56-57 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (67 Responses)	Non-EE/CE (32 Responses)
Laplace Transforms	10.5%	31.6%	21.0%	36.8%	56	91.9%	92.5%	90.6%
Ordinary Differential Equations	5.4%	37.5%	19.6%	37.5%	57	91.9%	91.0%	93.8%
Linear Algebra	3.5%	19.3%	31.6%	45.6%	57	84.9%	80.6%	93.8%
Difference Equations	8.8%	36.8%	19.3%	35.1%	57	71.7%	80.6%	53.1%
Z-Transforms	10.5%	31.6%	28.1%	29.8%	57	69.7%	80.6%	46.9%

Table 9 suggests that industry respondents place significant weight on the ability of control engineers to model physical systems. Detailed simulation models for product design and verification, real-time models for implementation verification, finite state machine models and others were cited as important or essential by a majority of respondents. Only linear models or "control-oriented" models were cited by a majority of academic respondents as being part of the curriculum for entry-level control engineers. "Experimental System Identification" stands out in Table 10 as an area considered important or essential by industry, but identified by less than half of university respondents as part of the curriculum.

Table 9: Mathematical Models of Physical Systems

	Industry Ranking (53-56 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (65 Responses)	Non-EE/CE (32 Responses)
Linear Models	3.6%	10.7%	39.3%	46.4%	56	95.9%	93.9%	100.0%
Control-oriented Models for System Design	1.8%	14.3%	50.0%	33.9%	53	67.0%	66.2%	68.8%
Simulation Models for System Verification or Product Development	5.5%	27.3%	43.6%	23.6%	55	48.5%	47.7%	50.0%
Nonlinear Models	9.1%	36.4%	34.5%	20.0%	55	42.3%	35.4%	56.3%
Finite State Machine Models	17.0%	26.4%	43.3%	13.2%	55	33.0%	33.9%	31.3%
Real-time Models for Hardware-in-the-Loop Verification or Training	5.6%	37.0%	38.9%	18.5%	56	25.8%	21.5%	34.3%
Model Reduction Techniques	14.3%	42.9%	33.9%	8.9%	54	16.5%	20.0%	9.4%
Finite Element Models (FEM)	36.4%	41.8%	18.2%	3.6%	56	10.3%	4.6%	21.9%
None						3.1	4.6	

Table 11 suggests PID design and PID tuning are important to industry: not a single respondent ranked either topic "not required." Table 13 suggests Model Predictive Control is an area of interest for industry that is not typically covered in a curriculum aimed at entry-level engineers. Robust control design, Table 14, is considered among the least important of control topics by industry respondents (H_∞ is part of the curriculum according to more than 60% of faculty respondents, but was considered "Not Required" according to 34% of industry respondents). Two topics that are apparently not typically part of the undergraduate/masters degree curriculum stand out as being considered relatively important by industry: Kalman estimators and model-predictive control (Table 13).

There were relatively few university respondents to questions regarding specification and requirements analysis of control systems. Industry response (Table 15 suggests there is industry interest in "noncore" topics such as formal real-time specification techniques and languages. Analog-to-digital conversion and quantization, characteristics of sensors and actuators, industrial systems programming (PLC, SCADA, for example), numerical methods and real-time software techniques were cited by more than 50% of industry respondents as being important or essential (Table 16). MATLAB^{TM}, Simulink^{TM}and LabVIEW^{TM}were the most commonly cited tools by industry respondents, and the most commonly taught tools according to university respondents. Thirty percent of industry respondents also cited Stateflow^{TM}as an important or essential tool; Less than 16% of university respondents cited Stateflow^{TM}as part of the curriculum (Table 17).

Finally, Table 18, "Other Topics," might suggest that "Networks and Distributed Control" is an area considered valuable by a significant minority of industry respondents (48.1% "important" or "essential"), that is not contained in a typical "entry-level" curriculum (23.3% of all faculty respondents).

Table 10: Modeling Methods

	Industry Ranking (56 Responses)				**University Curriculum**		
	Not Req'd	Useful	Important	Essential	All Faculty	EE/CE (64 Responses)	Non-EE/CE (31 Responses)
Block Diagram Models	1.8%	17.9%	25.0%	55.4%	94.7%	95.3%	93.6%
Signal-flow Graph Models	14.3%	35.7%	30.4%	19.6%	55.8%	55.8%	41.9%
Experimental System Identification	8.9%	37.5%	26.8%	26.8%	42.1%	42.1%	38.7%
Bond-graph Models	42.9%	44.6%	10.7%	1.8%	5.3%	6.3%	3.2%
None					2.1%	3.1%	
Other					2.1%	1.6%	3.2%

Table 11: Classical Control Design

	Industry Ranking (53-55 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (65 Responses)	Non-EE/CE (32 Responses)
Gain/phase Margins	9.4%	17.0%	30.2%	43.4%	54	89.7%	92.3%	84.4%
PID Design		5.5%	30.9%	63.6%	53	88.7%	89.2%	87.5%
Time Domain Performance Specifications	7.4%	13.0%	37.0%	42.6%	54	88.7%	87.7%	90.6%
Routh-Hurwitz Stability Criterion	25.9%	46.3%	9.3%	18.5%	54	84.5%	89.2%	75.0%
Lead, Lag, Lead-lag Compensation	3.7%	25.9%	33.3%	37.0%	55	72.2%	75.4%	65.6%
PID Tuning		7.2%	27.3%	65.5%	55	69.1%	72.3%	62.5%
Integrator Windup	3.7%	13.0%	35.2%	48.1%	55	36.1%	36.9%	34.4%
Sensitivity	7.4%	35.2%	35.2%	22.2%	54	29.9%	26.2%	37.5%
Loop Shaping	5.4%	40.0%	32.7%	21.8%	54	26.8%	24.6%	31.3%
Other						2.0%		6.2%

Table 12: Frequency Domain Analysis

	Industry Ranking (53-54 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (63 Responses)	Non-EE/CE (30 Responses)
Bode Plots	5.6%	20.3%	27.8%	46.3%	54	98.9%	100.0%	96.7%
Root Locus	9.4%	35.8%	32.1%	22.6%	53	82.8%	85.7%	76.7%
Nyquist Stability Criterion	11.1%	33.3%	27.8%	27.8%	53	76.3%	81.0%	66.7%
Other						2.2%	1.6%	3.3%%

Table 13: State Space and Modern/Optimal Control Design

	Industry Ranking (51-52 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (55 Responses)	Non-EE/CE (24 Responses)
Controllability, Observability	13.5%	26.9%	40.4%	19.2%	52	83.5%	87.3%	75.0%
Pole-placement using State Feedback	20.2%	50.0%	23.1%	7.7%	52	81.0%	85.5%	70.8%
Linear Quadratic Regulators	17.3%	42.3%	23.1%	17.3%	52	60.8%	61.8%	58.3%
Luenberger Observers	26.9%	38.5%	25.0%	9.6%	52	55.7%	56.4%	54.2%
Liapunov Stability Analysis	25.5%	45.1%	13.7%	15.7%	51	46.8%	47.3%	45.8%
Kalman Estimators	17.3%	23.1%	34.6%	25.0%	52	43.0%	41.8%	45.8%
Reachability	21.2%	51.9%	21.2%	5.8%	52	32.9%	34.6%	29.2%
Model Predictive Control	19.2%	34.6%	28.8%	17.3%	52	16.5%	14.6%	20.8%
Other						7.6%	3.6%	16.7%

Table 14: Robust Control Design

	Industry Ranking (50-51 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (28 Responses)	Non-EE/CE (10 Responses)
H_∞ Control Design	34.0%	46.0%	18.0%	2.0%	50	60.5%	53.6%	80.0%
Parametric Uncertainty and Unmodeled Dynamics	23.5%	43.1%	29.4%	3.9%	51	57.9%	53.6%	70%
μ Analysis for Structured Uncertainty	37.3%	47.1%	15.7%		51	21.1%	14.3%	40.0%
Other						7.9%	3.6%	20.0%
None						7.9%	10.6%	

Table 15: Specification and Requirements Analysis of Control Systems

	Industry Ranking (51-53 Responses)					**University Curriculum**		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (28 Responses)	Non-EE/CE (12 Responses)
Relational Database Systems and Structured Query Language (SQL)	32.1%	45.3%	20.8%	1.9%	53	35.0%	35.7%	33.3%
HTML/XML	38.5%	46.2%	13.5%	1.9%	51	37.5%	32.1%	50.0%
Unified Modeling Language (UML)	39.2%	35.3%	23.5%	1.9%	53	30.0%	25.0%	41.7%
Formal Real-time Specification Techniques/Languages	15.1%	45.3%	32.1%	7.5%	52	32.5%	32.1%	33.3%
Other						2.5%	3.6%	
None						5.0%	3.6%	8.3%

Table 16: Implementation of Control Systems

	Industry Ranking (52-53 Responses)					University Curriculum		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (64 Responses)	Non-EE/CE (29 Responses)
A/D Conversion and Quantization	5.7%	22.6%	37.7%	34.0%	53	71.0%	73.4%	65.5%
Shannon-Nyquist Sampling Theorem	7.7%	30.8%	32.7%	28.8%	52	64.5%	68.8%	55.2%
Characteristics of Sensors and Actuators		15.1%	37.7%	47.2%	53	62.4%	56.3%	75.9%
Microprocessor Architecture	11.3%	43.4%	32.1%	13.2%	53	61.3%	71.9%	37.9%
PLC, SCADA or other Industrial System Programming	23.1%	23.1%	21.2%	32.7%	52	47.3%	53.1%	34.5%
Numerical Methods for Real-time Integration	7.7%	36.5%	32.7%	23.1%	52	40.9%	32.8%	58.6%
Real-time Software Techniques	5.8%	25.0%	50.0%	19.2%	52	29.0%	26.6%	34.5%
Real-time Operating Systems (RTOS)	3.8%	45.3%	39.6%	11.3%	53	21.5%	26.6%	10.3%
Distributed Programming; Parallel Computing	28.9%	44.2%	19.2%	7.7%	52	5.4%	4.7%	6.9%
Other						4.3%	1.6%	10.4%

Table 17: Modeling, Design, Analysis and Implementation Tools

Tools Considered Important or Essential by more than 30% of 54 Industry Respondents	University Curriculum		
	All Faculty	EE/CE (66 Responses)	Non-EE/CE (30 Responses)
MATLAB™	99.0%	98.5%	100.0%
Simulink™	94.8%	95.5%	93.3%
LabVIEW™	43.8%	50.0%	30.0%
Stateflow™	15.6%	10.6%	26.7%

Table 18: Other Topics

	Industry Ranking (51-53 Responses)					University Curriculum		
	Not Req'd	Useful	Important	Essential	Num.	All Faculty	EE/CE (52 Responses)	Non-EE/CE (21 Responses)
Discrete-time Systems	3.8%	28.3%	35.8%	32.1%	53	82.1%	86.5%	71.4%
Phase Plane Analysis	27.5%	47.1%	23.5%	2.0%	51	38.4%	30.8%	57.1%
Adaptive Control	9.4%	47.2%	30.2%	13.2%	53	31.5%	34.6%	23.8%
Describing Function Analysis of Nonlinear Systems	17.0%	50.9%	20.8%	11.3%	53	31.5%	32.7%	28.6%
Networks and Distributed Control	23.1%	28.8%	26.9%	21.2%	52	23.3%	19.2%	33.3%
None						2.7%	1.9%	4.8%
Other						2.7%	1.9%	4.8%

5 Appendix

The first appendix contains verbatim survey questions. The last question of the survey solicited "any other thoughts you have related to the topic of this survey." These comments are also reproduced verbatim.

A Control Systems Society Survey on Control Curricula

The survey questions are enumerated in the following sections, delineated by those questions presented to university student respondents, questions presented to government/industry respondents, and questions presented to university faculty/staff respondents. All respondents were presented with a short description of the survey and its goals, and asked (but not required) to provide identifying and demographic information as follows:

> The IEEE Control Systems Society (CSS) Task Force on Outreach has developed this survey with the objectives of stimulating comments from industry and academia on capabilities and perceived shortcomings of entry level control engineers in industrial positions. Goals are to collect suggestions about how curricula can be improved, and establish a database of links to control course public web pages that may be used as a resource for educators and practitioners. The survey will require a few minutes of your time.
>
> Throughout, the survey uses the expression "entry-level control engineer" to denote fresh graduates with non-PhD (non-doctoral) degrees encompassing Bachelors, Masters, and equivalent.
>
> The Chair and Co-chair of the CSS task force on outreach, and the members of the task force will manage the data. The results of this survey will be published in aggregated form at the page:
>
> `http://www.ieeecss.org/`
>
> 1. Given Name
> 2. Last Name
> 3. Affiliation

4. Select your country (pull-down list)
5. Email
6. Where do you work?
   (a) Industry
   (b) University Faculty/Staff
   (c) University Student
   (d) Government
   (e) Other, please specify:

Depending on the answer to the question, "Where do you work?", a respondent was presented with one of the following three series of questions:

A.1 Questions Presented to "University Student" Respondents

1. What is your academic department?
   (a) Aerospace
   (b) Chemical
   (c) Civil
   (d) Electrical/Electrical and Computer
   (e) Industrial
   (f) Mechanical
   (g) Other, please specify:
2. What is your overall opinion of the capability of entry-level control engineers graduating in your discipline?
   (a) Excellent
   (b) Good
   (c) Fair
   (d) Poor
   (e) No opinion

   EXCELLENT: Solid understanding of systems and control fundamentals and facility with typical industry modeling, analysis and implementation tools; capable of working independently to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to make immediate individual contributions to the enterprise.

   GOOD: Solid understanding of systems and control fundamentals and acquaintance/familiarity with some modeling, analysis and implementation tools; capable of working with a mentor or with modest supervision to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to rapidly make contributions with experienced engineers as part of a team.

   FAIR: Understands systems and control fundamental concepts, but requires substantial additional training to model and analyze real-world industrial systems or implement solutions; can carry out tasks under the direction of an experienced engineer as part of a team.

   POOR: Does not have a good grasp of systems and control fundamentals, or is deficient in an important skill such as mathematics; requires substantial additional training before technical contributions to a team or project may be expected; requires explicit direction and supervision.

A.2 Questions Presented to "Government," "Industry," or "Other" Respondents

1. Typically, what is the academic background of entry level controls engineers hired by your organization (select as many as required)?
   (a) Aerospace
   (b) Chemical
   (c) Civil
   (d) Electrical/Electrical and Computer
   (e) Industrial
   (f) Mechanical
   (g) Other, please specify
2. What is your overall opinion of the capability of typical entry-level control engineers hired by your organization?
   (a) Excellent
   (b) Good
   (c) Fair
   (d) Poor
   (e) No opinion

   EXCELLENT: Solid understanding of systems and control fundamentals and facility with typical industry modeling, analysis and implementation tools; capable of working independently to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to make immediate individual contributions to the enterprise.

   GOOD: Solid understanding of systems and control fundamentals and acquaintance/familiarity with some modeling, analysis and implementation tools; capable of working with a mentor or with modest supervision to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to rapidly make contributions with experienced engineers as part of a team.

   FAIR: Understands systems and control fundamental concepts, but requires substantial additional training to model and analyze real-world industrial systems or implement solutions; can carry out tasks under the direction of an experienced engineer as part of a team.

   POOR: Does not have a good grasp of systems and control fundamentals, or is deficient in an important skill such as mathematics; requires substantial additional training before technical contributions to a team or project may be expected; requires explicit direction and supervision.
3. Do you have hiring authority, or do you participate in hiring decisions in your organization? (yes/no)
4. In your opinion, what areas (if any) need to be strengthened or added to the curriculum to better prepare control engineers for your industry? The areas need not be specific to dynamic systems and control, but may address prerequisite courses such as mathematics, or non-engineering areas such as economics, for example.
   (a) Basic Mathematics
   (b) Advanced methods
   (c) Industry-focused design
   (d) Mathematical modeling of dynamic systems
   (e) Hands-on experience

(f) Computer hardware and software
(g) No areas need to be strengthened.
(h) Other, please specify

BASIC METHODS: Classical and modern control methods and math courses typically expected of all undergraduate engineering students such as analytic geometry, calculus and elementary differential equations.

ADVANCED METHODS: Mathematics beyond what may be typically expected of all undergraduate engineering students (vector algebra, partial differentiation; line, surface, and volume integrals; linear algebra) and advanced control methods (Liapunov stability methods, adaptive and robust control).

INDUSTRY-FOCUSED DESIGN: Instruction in specific software packages such as MAPLE™, Mathematica™, MATLAB/Simulink™or other modeling and analysis tools widely applied in industry; basic control actions and industrial automation.

MATHEMATICAL MODELING OF DYNAMICAL SYSTEMS: Linear and nonlinear modeling for simulation, system identification, linearization and model reduction.

HANDS-ON EXPERIENCE: Laboratory implementation of controls using high-level (rapid prototyping) systems and academic hardware (inverted pendulum, Lego Mindstorms™, etc.).

COMPUTER HARDWARE AND SOFTWARE: Embedded microprocessor architecture, real-time software development, automatic code generation and other embedded implementation issues.

5. Which of the following topics do you think are important for control engineers entering your organization (rank each as Not Required, Useful, Important or Essential)?
   (a) Mathematical review and basic concepts
      (1.) Ordinary differential equations
      (2.) Laplace Transforms
      (3.) Difference equations
      (4.) Z-Transforms
      (5.) Linear Algebra
   (b) Mathematical models of physical systems
      (1.) Linear models
      (2.) Finite state machine models
      (3.) Nonlinear models
      (4.) Finite element models (FEM)
      (5.) Simulation models for system verification or product development
      (6.) Control-oriented models for system design
      (7.) Real-time models for hardware-in-the-loop verification or training
      (8.) Model reduction techniques
   (c) Modeling methods
      (1.) Block diagram model representation
      (2.) Signal-flow graph model representation
      (3.) Bond-graph models
      (4.) Experimental system identification
   (d) Classical control design
      (1.) Routh-Hurwitz stability criterion
      (2.) Gain/phase margins

(3.) Time domain performance specifications
(4.) Lead, Lag, Lead-lag compensation
(5.) Loop shaping
(6.) PID Design
(7.) PID Tuning
(8.) Integrator Windup
(9.) Sensitivity/Complementary sensitivity function

(e) Frequency Domain Analysis
(1.) Nyquist stability criterion
(2.) Bode plots
(3.) Root locus

(f) State space and modern/optimal control design
(1.) Linear quadratic regulators
(2.) Kalman estimators
(3.) Luenberger observers
(4.) Pole-placement using state feedback
(5.) Controllability, Observability
(6.) Reachability
(7.) Liapunov stabyility analysis
(8.) Model predictive control

(g) Robust control design
(1.) H_∞ control design
(2.) μ analysis for structured uncertainty
(3.) Parametric uncertainty and unmodeled dynamics

(h) Specification and requirements analysis of control systems
(1.) Relational database systems and structured query language (SQL)
(2.) Unified modeling language (UML)
(3.) Formal real-time specification techniques/languages
(4.) HTML/XML

(i) Implementation of control systems
(1.) Numerical methods for real-time integration
(2.) Real-time operating systems (RTOS)
(3.) Characteristics of sensors and actuators
(4.) Shannon-Nyquist sampling theorem
(5.) A/D conversion and quantization
(6.) Microprocessor architecture
(7.) Real-time software techniques
(8.) Distributed programming/parallel computing
(9.) PLC, SCADA or other industrial system programming

(j) Modeling, design, analysis and implementation tools
(1.) MATLAB™
(2.) Simulink™
(3.) Stateflow™
(4.) Mathematica™
(5.) Maple™
(6.) LabVIEW™

(7.) MATRIXx™
(8.) EASY5™
(9.) Web-based software
(10.) dSPACE™
(11.) ETAS™

(k) Other topics
(1.) Discrete-time systems
(2.) Describing function analysis of nonlinear systems
(3.) Phase plane analysis
(4.) Adaptive control
(5.) Networks and distributed control

6. Please include any other thoughts you have related to the topic of this survey.

A.3 Questions Presented to "University faculty/staff" Respondents

1. What is your academic department?
   (a) Aerospace
   (b) Chemical
   (c) Civil
   (d) Electrical/Electrical and Computer
   (e) Industrial
   (f) Mechanical
   (g) Other, please specify:
2. What is your overall opinion of the capability of entry-level control engineers graduating in your discipline?
   (a) Excellent
   (b) Good
   (c) Fair
   (d) Poor
   (e) No opinion

   EXCELLENT: Solid understanding of systems and control fundamentals and facility with typical industry modeling, analysis and implementation tools; capable of working independently to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to make immediate individual contributions to the enterprise.

   GOOD: Solid understanding of systems and control fundamentals and acquaintance/familiarity with some modeling, analysis and implementation tools; capable of working with a mentor or with modest supervision to model and analyze real-world industrial systems, and develop and implement control solutions. Could be expected to rapidly make contributions with experienced engineers as part of a team.

   FAIR: Understands systems and control fundamental concepts, but requires substantial additional training to model and analyze real-world industrial systems or implement solutions; can carry out tasks under the direction of an experienced engineer as part of a team.

   POOR: Does not have a good grasp of systems and control fundamentals, or is deficient in an important skill such as mathematics; requires substantial additional training before technical contributions to a team or project may be expected; requires explicit direction and supervision.

3. At your institution, entry level control engineering graduates typically require how many years of study?
   (a) 3 years
   (b) 4 years
   (c) 5 years
   (d) 6 years
   (e) More than 6 years
4. Typically, what degrees are granted to non-PhD entry level control engineers by your department/institution (for example, Diplom-Ingenieur, Masters, Bachelors, etc.)?
5. In your opinion, what areas (if any) need to be strengthened or added to the curriculum to better prepare control engineers for your industry? The areas need not be specific to dynamic systems and control, but may address prerequisite courses such as mathematics, or non-engineering areas such as economics, for example.
   (a) Basic Mathematics
   (b) Advanced methods
   (c) Industry-focused design
   (d) Mathematical modeling of dynamic systems
   (e) Hands-on experience
   (f) Computer hardware and software
   (g) No areas need to be strengthened.
   (h) Other, please specify

   BASIC METHODS: Classical and modern control methods and math courses typically expected of all undergraduate engineering students such as analytic geometry, calculus and elementary differential equations.

   ADVANCED METHODS: Mathematics beyond what may be typically expected of all undergraduate engineering students (vector algebra, partial differentiation; line, surface, and volume integrals; linear algebra) and advanced control methods (Liapunov stability methods, adaptive and robust control).

   INDUSTRY-FOCUSED DESIGN: Instruction in specific software packages such as MAPLE™, Mathematica™, MATLAB/Simulink™or other modeling and analysis tools widely applied in industry; basic control actions and industrial automation.

   MATHEMATICAL MODELING OF DYNAMICAL SYSTEMS: Linear and nonlinear modeling for simulation, system identification, linearization and model reduction.

   HANDS-ON EXPERIENCE: Laboratory implementation of controls using high-level (rapid prototyping) systems and academic hardware (inverted pendulum, Lego Mindstorms™, etc.).

   COMPUTER HARDWARE AND SOFTWARE: Embedded microprocessor architecture, real-time software development, automatic code generation and other embedded implementation issues.
6. The following questions refer to topics covered in a course or courses that you regularly or occasionally teach, and that would typically be completed by entry level control engineers graduating from your institution. If your course has a public website, and you would like a link to that website placed on the IEEE CSS web page, please enter the URL here:
7. Which of the mathematical review and basic concept topics in the following list would be expected of entry level control engineers graduating from your institution?
   (a) Ordinary differential equations

(b) Laplace Transforms
(c) Difference equations
(d) Z-Transforms
(e) Linear Algebra
(f) None
(g) Other, please specify

8. Which of the mathematical modeling topics in the following list would be expected of entry level control engineers graduating from your institution?
   (a) Linear models
   (b) Finite state machine models
   (c) Nonlinear models
   (d) Finite element models (FEM)
   (e) Simulation models for system verification or product development
   (f) Control-oriented models for system design
   (g) Real-time models for hardware-in-the-loop verification or training
   (h) Model reduction techniques
   (i) None
   (j) Other, please specify
9. Which of the modeling methods in the following list would be expected of entry level control engineers graduating from your institution?
   (a) Block diagram model representation
   (b) Signal-flow graph model representation
   (c) Bond-graph models
   (d) Experimental system identification
   (e) None
   (f) Other, please specify
10. Which of the classical control techniques in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Routh-Hurwitz stability criterion
    (b) Gain/phase margins
    (c) Time domain performance specifications
    (d) Lead, Lag, Lead-lag compensation
    (e) Loop shaping
    (f) PID Design
    (g) PID Tuning
    (h) Integrator Windup
    (i) Sensitivity/Complementary sensitivity
    (j) Other, please specify
11. Which of the frequency analysis topics in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Nyquist stability criterion
    (b) Bode plots
    (c) Root locus
    (d) Other, please specify

12. Which of the state space and modern/optimal control design topics in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Linear quadratic regulators
    (b) Kalman estimators
    (c) Luenberger observers
    (d) Pole-placement using state feedback
    (e) Controllability, Observability
    (f) Reachability
    (g) Liapunov stability analysis
    (h) Model Predictive Control
    (i) Other, please specify
13. Which of the robust control design topics in the following list would be expected of entry level control engineers graduating from your institution?
    (a) H_∞ control design
    (b) μ analysis for structured uncertainty
    (c) Parametric uncertainty and unmodeled dynamics
14. Which of the topics on specification and requirements analysis of control systems in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Relational database systems and SQL
    (b) Unified modeling language (UML)
    (c) Formal real-time specification techniques/languages
    (d) HTML/XML
    (e) Other, please specify
15. Which of the control system implementation topics in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Numerical methods for real-time integration
    (b) Real-time operating systems (RTOS)
    (c) Characteristics of sensors and actuators
    (d) Shannon-Nyquist sampling theorem
    (e) A/D conversion and quantization
    (f) Microprocessor architecture
    (g) Real-time software techniques
    (h) Distributed programming/parallel computing
    (i) PLC, SCADA or other industrial system programming
    (j) Other, please specify
16. Which of the modeling, design, analysis and implementation tools in the following list would be expected of entry level control engineers graduating from your institution?
    (a) MATLAB™
    (b) Simulink™
    (c) Stateflow™
    (d) Mathematica™
    (e) Maple™
    (f) LabVIEW™
    (g) MATRIXx™

(h) EASY5™
(i) Web-based software
(j) dSPACE™
(k) ETAS™

17. Which of the additional topics in the following list would be expected of entry level control engineers graduating from your institution?
    (a) Discrete-time systems
    (b) Describing function analysis of nonlinear systems
    (c) Phase plane analysis
    (d) Adaptive control
    (e) Networks and distributed control
    (f) Other, please specify
18. Which of the following are employed in a laboratory class expected of entry level control engineers graduating from your institution?
    (a) Purchased experiments
    (b) Custom experiments
    (c) Purchased Software
    (d) Custom software
    (e) None
    (f) Other, please specify

    Purchased experiments: Educational laboratories including all hardware and software supplied by companies such as Quanser, PendCon or Feedback Instruments Ltd, for example.

    Custom experiments: Educational laboratories which may include both purchased and developed hardware and software.

    Purchased control software: Students use MATLAB, LabView or similar commercially available tools to implement experiments.

    Custom control software: Students use C, C++, assembly or other language to implement experiments.
19. Please include any other thoughts you have related to the topic of this survey.

B Additional Comments from Respondents

B.1 Comments from Industry Respondents

Answers from industry respondents to the question "Please include any other thoughts you have related to the topic of this survey" are presented verbatim:

> Analyzing data using multivariate statistical analysis
>
> An entry level CSE should have a basic understanding of the basic closed loop control system (i.e., pressure, temperature, level, flow) applications and the dynamic response of these applications. These items could be easily incorporated into lab exercises. Generally, I find that a large number of entry level CSEs have excellent math skills, however, they are not experienced in applying these skills to the most common applications.

Most new grads seem to have a fair grasp of classical methods, but a poor understanding of modern control theory. This is unfortunate since most of our problems involve MIMO systems.

I work in the area of application of control for the Petrochemicals industry. 1. Understanding of regulatory and industry standards is a requirement. 2. As the area of Instrumentation and Controls is not a well crafted discipline at the university level, we get many of our entry level staff from community colleges, where there is a specific I&C trade stream. Many of these individuals do not have a deeper understanding of what goes on behind the obvious and I have found that this attitude, if not properly mentored, can get transfered to our university grads. 3. Human factors knowledge as it relates to the computer HMI is a skill that is universally not understood and has an unrecognized imact on the effectiveness of our work. This should also be looked at as an important educational input.

Students need to be able to translate classical control system theory into practical industry settings. They need to understand the importance of changing range/span on an analog instrument and the impact on loop tuning. I would also suggest electrical engineers need to take a fluid flow course to understand pressure drop and crane manual.

From my experience in completing my bachelor's degree, control systems received too little emphasis in the curriculum compared with other subjects within the electrical engineering department. In some cases, control classes were under required enrollment of students, and one control class I wished to take was canceled. I felt this was due to both a lack of interest in controls by faculty and lack of interest by students due mainly to no clear connection being made between the theory and the many practical applications of control concepts.

Basic topics in computer science (architectural patterns, finite state machines) ought be introduced in Master's-level programs. Most control systems development software(Simulink, LabVIEW) includes powerful tools for implementing advanced software design techniques, but very few entry-level employees have ever encountered these concepts before.

The exposure that Controls Engineers are getting to materials that they are going to use in the industry is limited to one manufacturer. I would prefer to see that they receive training on at least 2 major PLC platforms and VFD manufacturers. This will prepare them to the point that they should be able to run with whatever manufacturers equipment that they may have to once they get into the field.

The "modern" control engineer needs to be able to function in a muti-disciplinary environment. His basics (especially as regards math based understanding of processes & systems) must be sound AND, in an increasingly networked and "coupled" world, he must be taught to consider worst-case scenarios in all his work i.e. a course on Reliability should be taught even at the Bachelors level.

It would be nice to see new graduates (and PhDs) with a grasp of the various tracking modes, operational modes, and practical implementations of the humble PI controller (e.g. override select, directional blocking, etc.).

New engineers should have hands-on (touched real hardware) experience with a standard control systems design cycle: objectives, identification, off-line control design, implementation, validation.

Cross training in dynamics and vibration is beneficial.

As a controls engineer who has worked outside of aerospace, I would say the biggest problem is generating interest in upper levels of managment in having controls engineers. Support for this needs to come from demonstrating the advantage (speed, quality, features) of having controls engineers do controls work.

It is important that the industry companies be aware of different control and automation departments in the university, and it will be better if it gets unified in curriculum and naming all over the world. Morover, the students need to take some experience during their study to be easier for them to get integrated into the industry after qualification.

Especially at graduate level, I find extremely important that the students realize the computational load (in terms of CPU operations) of the advanced control strategies. Few examples are adaptive control schemes and optimization based control, where students have to realize whether the technique will be feasible for implementation or not. Numerical computation load is too often disregarded in class.

Classical methods still rule the day in my field (spacecraft controls and dynamics). Modern methods provide little additional benefit, and much unnecessary complexity.

I've worked in industry for the last three years and I think this is an important program. Many of the entry-level controls engineers in our organization lack the skills to design and maintain basic classical control systems. Unfortunately, most of these skills were introduced to them during their undergraduate education but were lost due to lack of use as the majority of their time is occupied with the installation and maintenance of hardware and software. I feel that it will be helpful in control education to place greater emphasis on some of the items in this survey. On the industry side we need to do a better job of encouraging controls engineers to continue to use these skills.

Real systems are quite complex. It is seldom we find only one solution which fits all criteria. I would expect a broader view on optimization, on how to tackle a problem in terms of practicabiliity, on how to mix different techniques to give differents choices and how solutions are affected by maintenance needs. Thank you for your survey.

In addition to the classical control and discrete control, the best thing for an entry-level controls engineer in the computer industry is to have programming knowledge and embedded systems knowledge.

Use of Finite State Machines is widespread in industry, but rarely taught at university. Also, general control concepts like internal models, tracking, and disturbance rejection are as important as classical techniques.

Controls curricula focus too much on math and not enough on physical intuition. Students generally think they know a lot about controls, but when faced with their first actual design task, they're usually at a complete loss. Give them more practice with bread-and-butter design problems.

At the moment I run my own company in power systems grid connection with no employees other than myself. In a few years I hope to have a few employees and then I'll be in a better position to answer all of this survey. Actually the area of control is highly important in my field.

Mixture of practcal work in industries and university

Control engineers need to be more holistic. Need to understand the physics of the application in at least some domains, be able to develop first principles based models and also be able to connect on the implementation level (real time, embedded implementation). The current curriculum emphasizes the mathematical theory at the expense of the practical realization aspects.

B.2 Comments from EE/CE Faculty Respondents

Answers from EE/CE faculty respondents to the question "Please include any other thoughts you have related to the topic of this survey" are presented verbatim:

The good background graduating students get are more oriented towards graduate work. Industry rarely uses more than PID and perhaps, fuzzy control and MPC. This leads to a vast knowledge gap that often leads to professional frustration when they realize that what they have been taught has no application. One can only hope that teacheing them the “Systems Approach” will eventually assist them in their careers.

The problem with the graduates in many US institutions is the huge difference between the top students (who are excellent) and the low end students (who do not belong in engineering). There is enormous pressure to water down curricula to keep students happy and the only rewards are for quantity and student “feel good” index as measured by “student evaluations.”

In addition to undergraduate classical controls and graduate state space analysis, I regularly teach the second semester senior design project. I have observed that, when faced with getting a (previously undesigned) real system to function, the first instinct for many students is to resort to hacking, abandoning the techniques, methods, and analysis that they have spent years developing and replacing it with a shotgun approach. They have a lot of difficulty in using analysis to help them debug a physical system. I think this results in part from the canned nature of earlier labs in the program. Increasingly, it is impossible to get the “wrong” answer on the labs. The experience debugging physical systems is sorely missed.

We are involved in the “Bologna” process and, then, we are preparing new curricula. Some questions can change, especially corresponding with experimental, real-time and industrial-used topics

The coursework at the Univ of S Paulo is exhaustive. There are opportunities for practical applied work in the yearlong senior project. The last thing we need are more specialized courses on controls and closely related areas. I have long pushed for a lower course load and more opportunities for multidisciplinary studies. With partial success I should add.

Most control system programs have missed that the majority of control-related jobs in the US are in the area of factory automation, which does not fit the mold of the classical linear control systems course. It mainly involves control of sequential processes using programmable logic controllers (PLCs) as the implementation platform. ISA (International Society of Automation) is already working on defining the curriculum of a program in Automation Engineering and seems to have stronger ties to the needs of industry.

At UPRM the undergraduate course of Introduction to Control Systems is required to our junior electrical engineering students . Actually some of our undergraduate students during their senior semester, they finish taking graduate courses in control like Nonlinear Systems and/or Optimal Control

To sum up the survey, I would like to add that all the courses related of Signal and Systems must be taught by teachers having very clear basic concepts. He and she must asses the strenght and weaknesses of the class and formulate a teaching strategy to teach the basic concepts of the Control System by initiating appropriate academic activity.

This was comprehensive. Some choices to questions seem to me to be low probability events. I cannot imagine that any entry level control engineer having some of this background.

We have a broad and generic program, because our industry is also broad. Moreover the engineering curriculum is a 5 year program that is gradually branching out into several specific master programmes of 2 years. The first 3 semesters are common for all engineering students and mainly deal with basic courses, including linear algeba, diffferential equations, and system theory. In the next 3 semesters the students can combine two domains (EE and CS, or EE and Mech). In the master programme we go in depth for topics like automation and mathematical engineering, electrical engineering, power engineering, mechanical engineering, computer science, nanotechnology... Suggestion : I certainly welcome initiatives set up by the societies of IEEE that share teaching material with the modern webmechanisms.

In control education, we have too much theory but not much real industrial applications. The most of the control society is living in a glass globe of advanced mathematical theories only interacting within themselves. All these energy and efforts produce very little return as real technological applications. Science must be useful for people, and there should be a good balance of theory and applications.

A good effort and I wish to be informed on the outcome. See also the link:

http://cm.akanewmedia.com/WebImages/NewsCast/Documents/Organization_7/ACC%20Panel%20Discussion%20_Oct29_Final_formatted.pdf

[ACC08 panel discussion report: What Skills Do Controls Engineering Graduates Need for Success? (acc08 photos)] entru page http://yangquan.chen.googlepages.com/

Our school graduates students with degrees in EE. We do not prepare students to be control engineers. A few of our students do wind up working in the field, however.

It is important that the control curriculum at universities be updated to prepare students for the challenges they would face in controlling networked hybrid systems. We should emphasize the interaction of control, communication, and computation in our undergrad control courses.

Needs a good number of additional faculty to teach and experiment in the area of Control Theory. Very few take interest in it because of heavy mathematical treatment in the course.

There are some topics that need to be reviewed from the classical syllabus that most institution follow in order to teach a basic contro course. pss tuning & optimization & neural network

B.3 Comments from non-EE/CE Faculty Respondents

Answers from non-EE/CE faculty respondents to the question "Please include any other thoughts you have related to the topic of this survey" are presented verbatim:

There is a wide variation in the course and project experience of students graduating from Princeton's Mechanical and Aerospace Engineering Department. The minimum requirement is MAE 433 for all MAE/BSE graduates (see course descriptions on-line). Most also take MAE 412, and some take MAE 345 (which I teach). A few take MAE 434. Students pursuing the aerospace option also will have taken MAE 331(which I teach)/332 or MAE 431/432. Senior thesis research often carries our students well beyond entry-level requirements, with work that is at the MSE level. Of course, not every MAE/BSE graduate is going to become a control systems engineer. All of them would qualify as entry-level controls engineers, and many of them go considerably further.

When answering the questions, I based the answers on students receiving an MS in control theory, not undergraduates. Also, the material that students learn at our university depends very much on whether they worked in a research lab and which lab. Any student in my lab does extensive work with embedded processing and real time systems.

As an educator, we need specific and general feedback such as will result from this survey. More communication and cooperation between industry and academ is needed.

I have always felt that the courses must have more math/physics/computational content than technological content such as MATLAB/Purchased Equipment. A young engineer must be able to contribute independently rather than carry out a senior manager's instruction. In an industry, though business is extremely important, there must be room for innovations from young engineers.

Undergraduate and graduate programs should but do not cover (1) fault detection and diagnosis, (2) design of min-max selectors with corresponding control systems, (3) optimal actuator/sensor placement, and (4) local nonlinear invertion and other simple nonlinear control methods.

In my environment, the curriculum contents are good on paper. However, the final effort required to pass a course should be higher... but cannot be, otherwise the number of students joining the courses will be low if they perceive control specialities to be significantly harder than others (local industry does not require too "advanced" methods, you can afford being harder if your graduates get better jobs, but it's not the case with our control engineers).

Interestingly enough, at The University of Nottingham the undergraduate controls course is going to be an optional module soon!

The above answers do refer to students who have taken ONE entry level course. Such a course is compulsory for all students in Stuttgart. Of course a rather large number of students do specialize in the control field and opt to take more courses (these are in average about three to five additional courses). Per year about 100 students do chose this specialization in the control area.

First, it is essential that students are taught HOW to use the techniques they learn in class to design controllers. Too often a mixed bag of techniques are taught, but there is no instruction or experience gained in actually USING these techniques to DESIGN controllers to meet a set of SPECIFICATIONS. Second, WAY too many courses only address plants which are SISO 2nd-order systems. Students need exposure to and controller design & analysis experience with higher-order MIMO systems with significant coupling BEFORE they go to industry.

Mathematical preparation is direly lacking in most undergraduate students. This makes it difficult for most to enter control systems meaningfully.

Control engineers should be trained to have intuition for the solution of a physical problem instead of just blindly working the math to get the solution. Also, it is of utmost importance to have lab experiments where the students can implement a controller on a real system. This will improve their learning and also improve their intuition because intuition comes from practice.

Good idea to make this survey. Please send me the results, this will help to convince within the faculty to allow time in the students' schedule to deepen their knowledge in modelling and control.

It is easy to over-emphasise mastery of techniques in Control courses, so that students can do clever things but do not know what is the ultimate purpose (e.g., how many can answer "Why do we use feedback for control?"). 2. The core difficulty in most control problems is in modeling and formulating specifications. Once those have been done, simple design/synthesis methods are usually enough. But it is hard/expensive to teach modeling and spec formulation in an academic course; it takes up a lot of time and is difficult to assess. I think this is a real challenge for Control educators.