A New Undergraduate Degree in Control Engineering

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***Abstract*—In December 1994, the Brazilian government regulated three new engineering undergraduate degrees. One such degree was in Control and Automation Engineering. The paper discusses how, in Brazil, Control Engineering moved from a relatively small group of courses within Electrical Engineering curricula to an undergraduate degree in its own right. It presents a short review of undergraduate control education in countries around the world. The authors also present an overview of the control engineering profession, real-life applications, and state-of-the-art in Brazilian industries. Finally, the paper describes the major issues taken into account during the conception of this new engineering degree at the Federal University of Minas Gerais, Belo Horizonte, Brazil. In 1998 and 1999 academic years, 40 students were admitted each year for this degree. In view of the high demand of the Control and Automation Engineering degree by the prospective engineering students, since February 2000, the number of places has been increased to 80 students per year.**

***Index Terms*—Control and automation engineering degree, control engineering education, control engineering in Brazil.**

I. Introduction

BRAZILIAN universities have been conferring engineering B.S. degrees since the early 1900s. However, the research in engineering started only in the 1960s with the beginning of the engineering graduate programs in Brazil. Since 1968, after a major reform, the Brazilian Universities in general have been following the North American University system, having their structure centered on academic departments.

In general, the Brazilian control engineering research groups belong to the Electrical Engineering Departments. Most of the early Brazilian control engineering professors had graduated abroad, in electrical engineering programs. The immediate consequence is that most of the control engineering teaching in Brazilian Universities has been performed in electrical engineering courses and has been, in general, theoretically oriented.

Although electrical engineering departments work well in control theory, the great majority of the Brazilian process engineering departments do not work with control engineering. They, essentially, do process engineering. Exceptions can be found in the aeronautic and aerospace area.

In the 1980s, under the demand from industry, mainly from the steel and oil industries, some control engineering research groups from electrical engineering departments began focusing upon process control problems. On the other hand, a few departments from the process engineering area started admitting professors with background in control engineering.

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Electrical engineering seniors began having courses in the control applications area. The control engineering undergraduate degree, created by the federal government in 1994, is a consequence of this movement toward the application of control theory to real industrial problems.

This paper presents the ideas and experiences supporting the Control and Automation Engineering undergraduate degree of the Federal University of Minas Gerais (UFMG), which began receiving students in the 1998 academic year. Among others, two papers presented in the IFAC/IEEE Symposium on Advances in Control Education, ACE2000, support strongly initiatives, such as the one described in this paper, that lead to the formation of the Control and Automation Engineers.

Antsaklis [1], in the first ACE2000 plenary session, stated that the field of control science and engineering is entering a golden age of unprecedented growth and opportunity. "Control systems technology is the cornerstone of the new automation revolution occurring in such diverse areas as household appliances, consumer electronics, automotive and aerospace systems, manufacturing systems, chemical processes, civil and environmental systems, transportation systems, end even biological, economic and medical systems" [1]. For Gruyitch and Nesic [2], the field of control engineering has reached its maturity as a scientific and engineering discipline. Analysis, synthesis, design, implementation, maintenance and development of control devices demand highly responsible, fully competent and complete Control and Automation Engineers.

The Control and Automation degree at UFMG fulfills the above-mentioned gap. The experience with this new engineering degree, in Brazil, began at the Federal University of Santa Catarina [3].

II. Undergraduate Control Engineering Education Around the World

An analysis of the undergraduate control education in universities around the world reveals different scenarios. Basically, they can be grouped in three different categories: 1) a few control courses in other engineering degrees; 2) engineering degrees with some specialization in control; and 3) a control engineering degree in its own right.

A. Few Control Courses in Other Engineering Degrees

This is the most common situation in which EE, ME, and ChE students take one to three one-semester courses in control. It can be found, among other countries, in the Arab countries [4], Australia [5], [6], Chile [7], China [8], Thailand [9], in many American universities, and in most Brazilian universities. The course programs, in these cases, range from Classical Control and Elementary State-Space Theory to Advanced Control.

In the United States, for example, the Control and Dynamical Systems Department at the California Institute of Technology, Pasadena, offers a one-year undergraduate control course for students in Mechanical Engineering, Chemical Engineering, Aeronautics, and Electrical Engineering [10]. At Carnegie Mellon University, there is a "designated minor" in automation and control comprising one undergraduate course each in fundamentals of controls, control system analysis and design, computing and software or control applications, and an additional elective in any one of the above areas [11].

In Brazil, most universities offer a relatively large number of (elective) courses from which the students choose the ones that best match their particular interests, in general, following predefined sequences of suggested subjects.

B. Engineering Degrees With a Major in Control

This scenario is present in some Japanese, German, South African, British and North American universities.

In Japan, although professors of control are scattered among a variety of departments (from Electrical to Biophysical Engineering, from Applied Mathematics to Industrial Management), departments of Control Engineering are present in most of the main universities. Several hundred Japanese students are majoring in Automatic Control every year [12].

Likewise, German [13] and South African [14] universities offer a specialization in Control Engineering. Ruhr University, in Germany, for example, is considering the increase in the mandatory control courses. They seem to be moving toward a full degree in Automation and Control Engineering [15], [16].

In France, engineering education is divided into a set of physics and mathematics courses, taken in a two-year period at a Preparatory School, followed by three years of engineering courses taken in a National School (Grande Ecole). At the National Polytechnic Institute of Toulouse, Electrical Engineering students have, in the first year, a general scientific education. The second year is centered in a specific education. In this year, automatic control and industrial informatics and signal processing are two of the three technological core areas. The third year assures the transition between theoretical study and the practical work of an engineer. Moreover, it may introduce the Advanced Studies Certificate in Automatic Control [17].

In Sweden, engineering education follows the central European systems with a 4.5-year program leading up to the degree "civilingenjör," which is equivalent to an M.S. in the U.S. and British system. At the Lund Institute of Technology, automatic control courses are taught as part of the engineering curricula in engineering physics, electrical engineering, computer engineering, mechanical engineering, and chemical engineering [18].

In the United Kingdom, where many of the more than 100 universities have significant teaching and research activities in control engineering, the basics of control are taught to all engineering undergraduates. Nevertheless, the Electrical and Electronic Department at Imperial College, for example, offers two-year core courses, which include a classical feedback control theory course. After that, two full years of control courses are taught to those students that take the control engineering option. In the University of Cambridge, on the other hand, the engineering curriculum provides an information engineering course, which covers very well classical control subjects in theoretical and lab classes. In their third and fourth year, students can take courses leading to a specialization in control and signal processing [19]. At the University of Oxford, the first year is common to all four (chemical, electrical, civil, mechanical) engineering courses; in the second and third years, five core subjects (covering the essential foundations of general engineering) are studied: Control, Dynamics, and Computers is one of these core classes. Two other areas to be studied in greater depth have to be chosen from five possibilities (basically the four engineering courses plus information engineering). In the final year, students can choose three specialist options, which generally follow up on the ones they have chosen in the third year [20].

Control courses at Stanford University in the United States are organized as engineering courses. They are developed and taught by the faculty of EE, ME, and Aeronautics and Astronomy departments. The EE seniors are required to take a sequence of specialty courses. Control courses comprise one of these sequences. The topics are introductory control, nonlinear control, and a control project laboratory where students design and construct a complete control system [21]. Princeton University offers a certificate program in Robotics and Intelligent Systems. Students working for a B.S.E. or A.B. degree in one of the traditional departments can earn the certificate by taking six qualifying courses and doing a senior thesis in the field. EE students may elect to concentrate in control and automation [22].

C. Specific Degree in Control Engineering

The literature review about undergraduate control education shows that universities in many other countries as well as in Brazil also offer a specific B.S. degree in control engineering.

In the United Kingdom, for example, the Department of Electrical Engineering and Electronics at the University of Manchester Institute of Science and Technology (UMIST) confers a degree in Communications and Control Engineering [23]. The University of Sheffield has a separate Department of Automatic Control and Systems Engineering, which offers its own degree with full coverage on all aspects of control theory [24].

Indian Universities offer degree in Instrumentation and Control [25]. In Australia, the Murdoch University offers a degree in Process Control [26]. In Greece, the University of Patras [27] and the Technological Educational Institute of Piraeus [28] offer curricula in Control and Automation. Specifically, the TEI Piraeus Automation Department offers a four-year curriculum divided into eight semesters. The focus of the curriculum is on automatic control theory and its industrial applications.

Control education in Russia has solid traditions. The technical institutes are graduating engineers in Automation of Industrial Processes since the early 1950s. Interestingly, the first Russian control textbook was published in 1909 by Prof. Gukovskii, who was teaching a control course at that time. Although much can be said about the contributions of Russian mathematicians in the early times of the control sciences, the control education in that country began in EE and ME departments. In the 1970s, the Institute of Automation and Remote Control (IARC) founded in

1939 had a staff of about 1800 working persons, including about 500 doctors and 500 engineers [29].

The Helsinki University of Technology (HUT) graduated, in 1997, 45% of all degrees in technology, in Finland [30]. The HUT Department of Automation and Systems Technology was opened in 1997 and, since then, every year 40 to 50 students are entering for a specific degree in the area [31].

In the United States, the MIT Department of Aeronautics and Astronautics, in 1999, moved toward a specific B.S. Degree in Control Engineering. They replaced their degree with two new degrees: 1) B.S. in Aerospace Engineering and 2) B.S. in Aerospace Engineering with Information Technology. While the former is a traditional aerospace engineering degree, with an emphasis on disciplines related to the engineering of aerospace vehicles, the new degree emphasizes the information technologies now necessary in the construction of modern aerospace systems. It reflects the Department's new thrust in Aerospace Information Engineering. There is an increased emphasis on information engineering with the objective of preparing engineers for the conception, design, implementation and operation of aerospace, and related engineering systems [32].

At Case Western Reserve University, the Electrical Engineering and Computer Sciences Department offers a B.S. degree in Systems and Control Engineering, which was the first of its kind to be accredited by the Accreditation Board for Engineering and Technology in the United States [33], [34]. They also offer a total of five (15 credit hours) courses to confer a minor in Systems and Control Engineering. There are three elective sequences available within their Systems and Control Engineering B.S. degree curriculum: 1) Control Systems; 2) Systems Analysis; and 3) Industrial and Manufacturing Systems [34].

There are similarities between the degree in Systems and Control Engineering at Case Western Reserve University and the new degree at UFMG, mainly in what concerns interdisciplinarity. Two main differences are that, at UFMG, students have a rather comprehensive set of formal process-related courses that provide special training and help develop specific skills. Another difference is that at UFMG the number of required courses is significantly greater; and, consequently, there is a greater variety of optional courses, all related to control engineering and automation; that students can choose from.

III. Control Engineering Practice in Brazil

The development of control engineering in Brazil followed the model of implantation of automation systems in the Brazilian industry. In its first phase, during the early 1970s, the steel and oil segments initiated a process of automation, importing systems from Japan, Europe, and from the United States. In this phase, Brazilian technicians learned how to use instruments produced abroad and basic control techniques, like tuning of PID controllers. The next phase was associated with the government decision of restricting the importation of digital equipment. This decision forced Brazilian companies to develop their own products, sometimes, in association with a technological partner.

The aeronautical industry, mainly using highly qualified Brazilian engineers and doctors, graduated mostly in France and the United States, became the leader in the application of advanced control engineering. The local industry was capable of producing basic instruments, such as digital controllers and computers for use in process control. Some well-established international companies, such as Digital Equipment, Hewlett Packard, Bailey, Fisher Controls, etc., maintained their positions importing spare parts or producing equipment, following a nationalization program. The control revolution, at this point, reached basically the more sophisticated and money intensive industries: paper, steel, petroleum and gas, chemical and minerals.

In this phase the goal was to accomplish basic control tasks and process supervision. Traditional operating panels with conventional bottoms, lamps and thumbwheel-conducted operations were used. Later, the use of Programmable Logic Controllers in substitution to relay logic became popular and distributed control systems and SCADA systems were installed.

In the 1990s, with the opening of the Brazilian economy, a whole spectrum of international products became available; and, as a consequence, the control community matured. The participation in international societies like IEEE and ISA (The International Society for Measurement and Control) became popular among professional engineers.

The target in Brazilian industries, nowadays, is not only to achieve process control, operation and supervision, but mainly process optimization. The concerns with personnel reduction and energy savings associated with the international competition, which increase pressure to reduce production costs and improve product quality, forced the more traditional industries into the process of automation. The very conservative cement industry suffered a drastic modernization with the adoption of automation, including optical temperature scanners, on-line gas analyzers up to real time expert systems that were used for the full automation of kilns and grinding circuits. Foods, beverage, automotive, and, even familiar industries, like clothes and shoes; all began an urgent process of automation.

The relatively low price of the automation products allows a whole class of small companies to follow this trend. The products involved are very up-to-date. A new class of control companies is being created in Brazil. They are facing the international competition and are exporting equipment and systems. Those companies are selling products like programmable logic controllers, fieldbus instrumentation, SCADA systems, and dedicated aluminum pot line automation systems, just to mention some, to several countries including the United States and European countries.

In this scenario, the proposition of a specific undergraduate degree in Control and Automation Engineering became natural.

IV. Reasons for a Self-Contained Degree in Control and Automation Engineering

Systems and control engineering is a "cross-disciplinary" discipline. In general, engineers seek problem solutions from their own area. Control engineers analyze and solve engineering problems combining different technologies, across

the boundaries between disciplines. Many of the fundamental tools of the field arise from applied mathematics, computer engineering, and computer science. The range of system design, analysis, and control problems includes industrial and management systems, biological and environmental systems, and economic systems [32]. The need for Control and Automation Engineers in this coming century will strongly increase [2].

The systems and control engineering B.S. program shall provide the students with the basic concepts, analytical tools, and engineering methods, which are useful in analyzing and designing complex technological and nontechnological systems. Problems relating to modeling, decision-making, control and optimization must be studied. The relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating their individual contributions to achieve the overall goal of the system. What may be best for an individual component of the system may not be the best for the system as a whole.

Therefore, the control engineers must have an engineering education that yields the ability to develop an integrative work. Such a professional can be considered as a systems engineer oriented to the design, implementation, use, management, and maintenance of automatic systems.

In the great majority of Brazilian universities, control courses have been seen as part of the EE degree. However, the new Bachelor degree in Control and Automation Engineering, as presented in the following sections, fundamentally differs from that of electrical engineering in the following aspects.

1) It can be seen as a "horizontal" (multidisciplinary) degree covering a wider range of subjects.
2) The field of application of the degree ranges from biological, chemical, thermal, automotive, electric, mining and metal systems, to domestic, commercial and banking systems.
3) The degree in Control and Automation Engineering is concerned with the process to be automated or controlled, not exclusively with the electrical/electronic equipment.
4) In the last two semesters of the course, students will be asked to develop a complete design (called "Final Year Project") for a system they have chosen to automate.

The Control Engineer has to be prepared to work in the process industries as well as in the control hardware and software maker companies. The students are educated to: 1) conceive and install automatic production units; 2) perform changes in order to operate old production units in an automatic way; 3) maintain and optimize automatic production units; and 4) specify, conceive, develop, and implement hardware and software for control and automation.

The previous arguments seem to show that neither electrical engineering nor any other conventional degrees in engineering is capable of giving the necessary background for a student who wants to work professionally in control and automation. Furthermore, the complexity and diversity found in control theory, process modeling, and on-line computer control requires a better and deeper understanding of the particular problems of each field of application.

V. The Control and Automation Engineering Curriculum at UFMG

A. General Aspects

As established in 1994 by a Brazilian Ministry of Education Regulatory Act, the basic technical formation subjects are mathematics, physics, chemistry, computer sciences, and transport phenomena. The general education subjects are humanities, law, economics, and environmental sciences. The general technical classes are Process Control, Industrial Systems, Instrumentation, Discrete Mathematics for Automation, Industrial Informatics, Systems Integration, and Evaluation and Production Systems Management. Each University, after teaching the subjects pointed out above, can complement the degree with other specific subjects, taught in courses that best characterize its own degree.

The new curriculum at UFMG has been designed to enable the Control and Automation Engineer B.S. to: 1) Develop mathematical models of dynamic processes and systems; 2) evaluate control systems performance; 3) establish control strategies to yield adequate system behavior; 4) specify subsystems, modules and parts for sensors, controllers, and actuators; 5) tune controllers; 6) deal with the main problems arising from nonlinearities and dead times in control systems; 7) apply advanced control techniques; 8) Apply the main languages and operating systems used in the control and automation engineering area; and 9) develop, in an adequate language, communication software among units and for the man–machine interface.

B. Courses in the Curriculum

1) Curriculum Overview: Table I shows a synthesis of the courses' credit hours, grouped by subjects. The total number of hours is 3660, to be accomplished in five years, in two annual 15-week terms.

Apart from boosting students' motivation, the inclusion of specific professional cycle courses since the first semester aims at bridging the gap between basic knowledge (mathematics and physics) and engineering applications.

The innovations of the Control and Automation Engineering degree, in comparison to other Brazilian engineering degrees are: 1) The total time spent in lectures has been reduced; 2) the degree relies on multidisciplinary projects which require an active attitude by the student, especially in laboratories; 3) the academic activities of two consecutive semesters have been concentrated in the mornings in order to allow the students to get part-time training jobs in the afternoons; 4) optional courses in entrepreneurship area are provided for the more business-minded students; 5) most process engineering departments have been involved, with optional courses in the curriculum; and 6) a "final year project" course has been included as a means of assessing both student and degree success.

Finally, another innovative policy is the concern about contacts among the students and the real engineering work market. To accomplish this goal, all students, in groups of two, are sent for short-term (one week) technical visits to the area companies. These visits occur twice a year, during the school vacation periods after the first semester. The technical visits, arranged by the University, are organized such that a student shall not repeat

TABLE I
COURSES CREDIT HOURS

Basic Cycle:	
Mathematics	26
Physics	29
Chemistry	7
Basic Programming	16
Professional Cycle:	
Basic Engineering	9
Humanities	6
Electronics & Electrical Eng.	25
Computer Engineering	9
Control Theory	22
Control Labs	14
Automation	12
Production Engineering	16
Final Year Project	10
Optional courses	43

a visit to the same company. This program of visits has had a smashing success among the students.

In the last two years, the students will be encouraged to take part-time positions as trainees in companies around the campus area.

2) Optional Courses: During the professional cycle, besides some compulsory courses, the student will take 645 hours of optional courses. They can be chosen, under supervision of a faculty member, from the following sets:

- *Process courses*: The aim of each course is to describe the respective area processes, namely: 1) chemical, 2) metallurgical, 3) mineral, 4) transportation, 5) biological, 6) electrical, 7) thermal, 8) automotive, 9) manufacturing.
- *Control Engineering*: 1) system modeling techniques, 2) stochastic processes, 3) stochastic control, 4) introduction to adaptive control, 5) multivariable control, 6) topics in process control, 7) topics in control theory, 8) topics in industrial instrumentation, 9) topics in automation and control.
- *Artificial Intelligence*: 1) fuzzy systems, 2) artificial neural networks, 3) introduction to database systems, 4) topics in robotics, 5) topics in artificial intelligence.
- *Industrial Computing Systems*: 1) automation system programs design, 2) computer-aided design and manufacturing.
- *Electrical Engineering*: 1) industrial electricity, 2) electromagnetic compatibility for control, 3) communication principles.
- *Production Management Engineering*: 1) managing the development of industrial automation systems, 2) operational safety and reliability.

Altogether, 19 departments serve the control and automation degree at UFMG. A board runs the degree with members appointed by the departments with major involvement in the curriculum. There is also a student representative. The board is responsible for all academic matters related to the degree, such as: prerequisite chain, course programs, etc. The departments, on the other hand, supply the necessary resources to keep their own courses running: professors, lecture rooms, laboratories, etc. The degree board establishes, from a set of courses offered by the departments, the ones that best compose the curriculum.

VI. PERSPECTIVES OF THE IMPACT OF THE NEW ENGINEERS IN THE BRAZILIAN ENGINEERING

At first sight, one could imagine that the new undergraduate degree represents an over specialization. However, Case Western Reserve University officials claim that their Systems and Control Engineers find positions in both the private and in the public (governmental) sector. About half enter graduate school, where they are valued because of the general purpose engineering problem-solving skills that they possess and because they are especially capable of adapting to new technology changes [34].

The argument of those against a specific degree in Control and Automation Engineering is that undergraduate courses should give the students a sound basis for future development and specialization; an excessive emphasis in control theory could distort the student formation in detriment of more general concepts, generally found in electrical engineering programs. In this line of thought, automation seems to be more appropriate as an emphasis of the traditional Electrical Engineering degree than a new degree by itself.

The reality is just the opposite. The new Control and Automation Engineering curriculum is, in fact, a more general program than the traditional engineering degrees. The students will receive a broad formation involving courses of several engineering departments: electronics, electrical, computer sciences, mechanical, chemical, metallurgical, mining and industrial production. The aim is to have a professional fully capable of understanding a complex environment and finding appropriate solutions based on a secure and formal ground formation in several fields.

It is unusual to find an electrical engineer as the Industrial Director or Chief Executive Officer (CEO) of an industrial plant in Brazil. Process-related engineers have greater advantages in such a competition. Chemical, metallurgical, mining, and mechanical engineers are more at home when deciding about the concepts that guide the future of a chemical, petrochemical, pulp and paper, mineral, steel, fertilizer, and other process-based plants. They are more used to discussing the physical phenomena at the heart of the industry's business. From the beginning of their careers they will be involved in the main organization's issues, discussing management operation and research problems with top managers and will occupy the main positions. Electrical engineers, on the other hand, have a somewhat side career, acting as a support professional.

The authors expect that the control and automation engineer graduated at UFMG will have the necessary skills to be a confident person and will be a serious candidate to the best positions. He/she will know about the phenomena taking place in many process industries, will have a solid foundation in the

control and automation solutions, and will know which decision-making tools are the more appropriate. Automation knowledge means not only instrumentation and control, but also the technologies that today allow managers and directors to make decisions. They will be familiar with Manufacturing Execution Systems (MES), supply chain concepts, value chain administration, Enterprise Research Planning (ERP), and related concepts.

The market for the new engineers will not be restricted to industries, control equipment manufacturers, and system integration companies. The Enterprise Production Systems (EPS) market, in South America, is expected to grow at a rate of 20%, until 2003 [35].

The University must give the students a solid basic engineering education, but not training for specific tasks only. Presenting the students with a rich spectrum of theories in many different areas of the engineering will improve their chances of future specialization and development.

On the other hand, practical experience provided to the students, since the early years by the programmed technical visits, by the lab work throughout the whole course, and by part-time positions as trainees in companies during the last two years will make them competitive in the professional job market.

Today, there is a lack of skilled professionals to perform more sophisticated technological tasks in the Brazilian companies and industries. It is almost impossible to find engineers with good knowledge in control theory, instrumentation, software development, and, at the same time, some knowledge about the process to be controlled. This situation is mainly a result of the way knowledge is divided in most engineering schools worldwide. Therefore, the new control and automation engineer will find an open way to follow. There are opportunities to build models, to optimize control systems, to employ new technologies like expert systems, fuzzy logic, and neural networks, and to develop software to integrate all levels of control from the factory floor to the management level.

To be able to optimize a control system, the engineer must have a deep understanding of the process to be controlled. This is a very difficult task for the conventional, theoretical, electronics-based, control engineer. It requires formal training instead of the slow "in-the-field-osmosis" learning, usually observed in practice. This asks for a full and autonomous Control and Automation Engineering bachelor degree.

VII. Conclusion

This paper has described the main points concerning the conception of a new undergraduate, five-year degree in Control and Automation Engineering, in Brazil. From a legal standpoint, this degree has been created as a consequence of a federal government act, issued in 1994, that regulates three new engineering degrees in the country. The paper skims through the situation of undergraduate control education in many countries. It discusses today's situation of the control engineering practice in Brazil. It presents the main characteristics of the new curriculum and discusses in what sense Control and Automation Engineering graduates will be different from electrical engineering graduates who have majored in control engineering.

Because of the multidisciplinary nature of the courses, the new control and automation engineers will certainly be better prepared to face the challenge of the world with ever-changing technologies.

From a practical point of view, the new degree can be seen as a response to an ever-increasing demand for an engineer with specific background in control. This new engineer will face the challenges of helping the nation's engineering in setting a big country in the pace of modernity.

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