Real-Time Software-Intensive Systems Engineering: An International Perspective

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***Abstract*— This paper provides an overview and a comparison of several international projects which focus on research and development of international computing curricula. The projects address computer based systems in general and more specifically the area of real-time software intensive control systems. Issues related to the analysis, design, implementation and assessment of such curricula are discussed. The paper also deals with the exchange of students and faculty between international academic institutions.**

I. Introduction

The analysis, design, implementation, administration, and assessment of international curricula are becoming increasingly important in the global community of the 21st century. In support of this critical issue, the European Commission and the US Department of Education have funded the ATLANTIS initiative to promote collaboration in higher education between European and American universities.

Recently completed, the ILERT (International Learning Environment for Real-Time Software Intensive Control Systems) ATLANTIS project has been involved in the creation of a bachelor degree international curriculum framework centered on RSIC (Real-Time Software-Intensive Control) systems. The ILERT study explored a mechanism for involving students from multilingual, geographically separated institutions in a coordinated educational experience. The ultimate objective of this two-year ATLANTIS project was creation of an RSIC curriculum model, which can be used by engineering schools both in the USA and the EU.

The main objective of the currently launched ATLANTIS continuation project DeSIRE[2] (Dependable Systems International Research and Education Experience) is to establish a platform for a sustained and consistent mobility exchange of graduate students engaged in RSIC oriented programs. These programs need to produce graduates capable of working efficiently in multidisciplinary teams participating in international collaboration on industrial RSIC projects, which require conformance to specific standards mandated by regulatory authorities.

This four-year Excellence in Mobility project is proposed by a consortium of three American and three European university partners. The project proposes mobility exchange of students pursuing graduate (Master level) engineering degrees in the areas supported by the consortium partners. The plan is to implement a mechanism for involving students from multilingual, geographically separated institutions in a coordinated educational experience exposing them to the problems, methods, solution techniques, infrastructure, technologies, regulatory issues, and design/verification tools usually not available in their home program. Four of the six consortium partners participated in the preceding ILERT project.

The paper discusses in the next section the first experience with international development of a related set of study programs for ECBS (Engineering of Computer-Based Systems) developed by the IEEE CS TC-ECBS Education and Training Workgroup that was devoted to the same engineering domain. Following sections provide more detailed information on ILERT and some information available on DeSIRE[2].

II. ECBS EDUCATION AND TRAINING

Many modern systems are Computer-Based Systems (CBS). They are systems whose behavior is, to a substantial degree, determined or controlled by computers. Typically they are complex and consist of many networked, geographically distributed subsystems. Each system or subsystem may be or may contain a multi-computer system. They are intensively dependent on software, and frequently depend on data communication networks, human-computer interaction, and special hardware. They may be internal to the developed systems, for example in a medical instrument, or "external" to the developed system, for example the CBS controlling a chemical plant.

CBS span a wide range of applications. Examples include; telephone and communications systems, real-time embedded computer systems such as process control and computer integrated manufacturing systems, transportation systems (automotive control, train control, ship control, traffic control), commercial management information systems such as airline reservations, payroll information, stock control, electronic banking systems; avionics systems, missile control systems, medical instruments, microcomputer controlled domestic appliances and point of sale systems.

The development of such systems requires a special engineering discipline that has been termed the Engineering of Computer-Based Systems (ECBS). It is similar to other engineering disciplines such as electrical and mechanical engineering. It integrates many engineering technologies or subjects such as hardware engineering, software engineering, communications engineering, principles of systems engineering, and others.

The current section presents basic features of ECBS curricula designed by the Working Group on Education and Training of the IEEE Computer Society ECBS Technical Committee. The first curriculum focused on the ECBS Master program developed by the Working Group at its meetings during the ECBS96 and ECBS97 Conferences in Friedrichshafen, Germany, and Monterey, California [1], [2]. One of the first implementations of this program was presented at the ECBS98 in Maale Hachamisha, Israel [3]. At this conference, there was also introduced the compatible Bachelor's program developed by the same Working Group [4]. Subsequent meetings were aimed at ECBS training courses for industry [5], [6].

A. Master degree curriculum

The objective of the proposed program is to educate and train its students giving them a good understanding of the nature and challenges of the engineering of computer-based systems. They will graduate as engineers capable of defining, developing, implementing, maintaining and evolving complex computer-based systems, using available theoretical and practical methods, techniques, tools and standards. Applicants to the program should satisfy the following requirements:

- First degree in any of an Engineering discipline, Physics, or Computer Science;
- Completed the following prerequisite courses: calculus, discrete mathematics, probability and statistics, physics, digital electronics, computer architectures, data structures, operating systems;
- Working knowledge of programming and preferably a year of industrial experience of developing CBS.

The program is composed of three tiers:

- First, the basic tier includes essential units covering constituent technologies necessary in the development of CBS;
- Second, the core tier is composed of five courses and a number of elective courses;
- Third, the practice tier of the program is a project to construct a real CBS.

B. Bachelor degree curriculum

The aim of the ECBS Bachelor program was to educate students about the nature and challenges of the engineering of computer-based systems and applications. ECBS graduates are expected to be able to define, develop, implement, test and maintain evolving computer-based systems, using available theoretical and practical processes, methods, techniques, and tools, adhering to present standards and codes of professional conduct. The program will focus on developing the students' capabilities to function as integrators of concepts, methods, and technologies, taking a systems approach. The program does not compete with more specialized, detailed curricula in each of the sub-domains encompassed within ECBS, such as software engineering, electrical engineering, or communications. Instead, graduates of the proposed program will rely on more specialized experts to treat the sub-domains in detail.

We divided the topics to be taken during the ECBS undergraduate program into the following eleven groups:

- Mathematics
- Sciences
- Engineering
- Computing
- Communication Engineering
- Software engineering
- Computer-Based Systems Engineering
- Engineering management
- Supporting Processes and Skills
- Applications and Projects
- Electives

The following topics should be covered in the suggested groups in form of course modules:

- Calculus for engineers
- Mathematical logic
- Discrete mathematics
- Probability and applied statistics
- General physics (calculus based)
- Fundamentals of electrical engineering
- Electronic circuits
- Digital systems principles/logic design

- Fundamentals of control and instrumentation
- Information theory and signal processing
- Systems simulation and modeling
- Computing
- Programming
- Computer algorithms and data structures
- Programming languages and operating systems
- Computer organization
- Parallel and distributed systems
- Embedded systems and real time systems
- Communication Engineering
- Computer networks and interfacing
- Software Engineering
- Software architectures and components
- Software analysis, design and CASE tools
- Software verification and validation
- Introduction to ECBS and CBS applications
- CBS modeling, requirements and specification
- CBS architectures and CBS components
- Human/Machine interfacing
- CBS design and performance analysis
- CBS integration, verification and validation
- CBS evolution and legacy systems
- CBS Project management
- Communications skills
- Electives
- Individual projects
- Final group project

After Bachelor degree curriculum implementation, the Master degree implementation was considered to be improved into a more advance form.

III. ILERT FRAMEWORK

The main objective of the project has been to establish a methodology for creation of multinational, engineering program producing graduates capable of working efficiently in multidisciplinary teams engaged in international collaboration on industrial projects, requiring conformance to specific standards mandated by regulatory authorities. Considering the demand for efficient development of quality RSIC systems, in this two-year policy-oriented project engaging four university partners, we propose a study leading to establishing international curriculum framework focusing on this important aspect of the computer/system/software engineering education [7].

On-site research by the project faculty was enhanced by frequent communications and dedicated working sessions at the partners' sites. The partners focused on the RSIC aspects of computer, system, control, and software engineering curricula and designed a case-study: experimental concurrent delivery of a selected course to on-site students.

The project ILERT led to creation of a model RSIC curriculum accepted by partner institutions, which can be used by other engineering schools in the US and the EU. This project encompassed the design of an international RSIC learning environment, curriculum framework, identification of implementation and assessment mechanisms, collection of data necessary to evaluate the process, and guidelines for expansion of the proposed approach to other engineering programs [9]. The project can be reviewed according to the following phases: Preparatory, Research, and Implementation.

A. Preparatory phase

The Preparatory phase was launched by informal discussion between the faculties of the academic institutions on both sides of Atlantic about advantages of international relationships. The following items identify the activities of this phase:

- *Inventory of international informal personal contacts already existing in institutions.*
- *Brainstorming on the type of activities to be engaged, potential partners, defining goals and priorities* (curriculum-related cooperation and international exchanges of the faculty expertise).
- *Proposing an initial consortium of universities offering expertise in the similar lines of engineering education.*
- *Identifying the focus areas in the existing programs of the consortium partners.*
- *Exploring potential for financial support* (including industry funding, international cooperation programs, international projects, international and national systems of grants).

The Research phase started with analysis of industry requirements related to graduates in the proposed domain. The collected data were analyzed [8], and the results were used to help identify academic program learning objectives and outcomes, i.e. a base for curriculum framework.

- *Defining learning objectives and outcomes, identifying the curriculum framework, exploring the partners' programs commonalities, laboratory infrastructure, identification of the curriculum content, and analysis of the educational process assessment.* The existing curricula were reviewed as a way of prioritizing and integrating the various elements in order to fulfill the requirements of interdisciplinary specialization. As the final outcome of this phase a comprehensive list of courses related to RSIC domain offered at all of the partner institutions was compiled.
- *Developing curriculum.* The courses were classified into one of the four categories: General Education (languages, humanities, social science), Math and Science, Basic (required towards the completion of the degree in the given line of study), and Advanced (focusing on specialty areas related to the selected engineering specialization). A sequence of courses was proposed. *Case study: Creating an engineering program acceptable for all partner organizations.*
- *Credit transfer and accreditation issues.* The development of new curriculum framework in engineering may in turn require new approaches to their validation and accreditation. The transfer of credits and grades is a challenging undertaking for

university systems which are significantly different in Europe and U.S. Existing and emerging structures for accreditation, quality control and credit transfer (such as the European Credit Transfer and Accumulation Scheme) have been analyzed and coordinated. The proposed curriculum units must be reviewed according to ABET standards and the applicable standards of Ministry of Higher Education in the European countries, focusing on the objectives and outcomes of the educational activity, see [9].

This phase was concluded by formal establishment of the consortium of university partners (i.e. Embry-Riddle Aeronautical University, USA, AGH University of Science & Technology, Poland, Brno University of Technology, Czech Republic, and Grenoble University, France) and submitting a successful proposal for an educational research project.

B. Research phase

- *Students' mobility plan.* Based on the developed curricula a general schedule of students' mobility between partners' institutions can be proposed, opening possibility of collaborating and enrolling in the courses offered in four partner sites.
- *Formalizing the activities.* This activity can include: signing formal agreements or memoranda of understanding, defining responsibilities and structure of communication.

To demonstrate more concrete results of this phase, the rest of this subsection provides a review of the RSIC framework through its basic organizational units [10]. The basic organizational unit for the framework is a RSIC "component". A RSIC component is a curriculum unit which covers theory, knowledge and practice which supports the RSIC curriculum objective and outcomes. Table 1 describes the RSIC components in six identified RSIC areas: Software Engineering, Digital Systems, Computer Control, Real-Time Systems, Networking, and Systems Engineering.

The RSIC Curriculum Framework does not specify the way in which component topics might be formed into modules or courses. Component topics might be focused in one or two courses, or spread among several courses, along with other non-RSIC topics. The curriculum framework includes more detailed specifications of each component: prerequisite knowledge, component learning objectives, information about required facilities and equipment, and guidelines and suggestions for course design and delivery. The RSIC curriculum framework also makes recommendations about non-RSIC courses or units that should be part of a RSIC program, as prerequisite courses or to supplement the components as part of a full degree program. The recommendations call for courses in the following areas:

- Mathematics (Differential and Integral Calculus, Differential Equations, Discrete Mathematics, Statistics, Linear Algebra)
- Physics (mechanics, E&M, thermo, fluids)
- Electrical Engineering (circuit analysis, basic electronics)
- Engineering Economics
- Introduction to Computer Science with Programming

TABLE I
RSIC COMPONENTS

Software Engineering
Software engineering concepts and practices, software lifecycle models, project management, software processes, software modeling and formal representation; software requirements; software architectural and module design; software construction methods and practices, testing and quality assurance; software maintenance; and notations and tools.
Digital Systems
Concepts, methods, techniques, and tools used to support the design of combinational and sequential digital circuits and the design of fault tolerant and advanced networked hardware components.
Computer Control
Concepts of feedback control, time and frequency domains, continuous and discrete models of dynamical systems, state analysis, stability, controllability and observability, controller design, implementing control algorithms in real-time, integrated control design and implementation, use of analysis and design tools.
Real-Time Systems
Timing and dependability properties of software intensive systems, RTOS concepts and applications, concurrency, synchronization and communication, scheduling, reliability and safety, etc.
Networking
Data communication, network topology, analysis and design, information security, algorithms, encryption, bus architectures, wireless, etc. distributed control and monitoring
System Engineering
System engineering concepts, principles, and practices; system engineering processes (technical and management); system requirements, system design, system integration, and system testing; special emphasis on the development of a RSIC system, the integration of RSIC elements.

C. Implementation phase

The Implementation phase is dealt with in [10]; moreover, it is demonstrated by a case study on a combined RSIC-SE2004 curriculum, i.e. ILERT and the Software Engineering efforts of the ACM/IEEE-CS Joint Task Force on Computing Curricula, see [11]. Further implementations will appear in relation to the DeSIRE^2 project, see next section and [12], [13], [14].

IV. DeSIRE^2 MOBILITY

With an abundance of applications interfacing with and controlling the environment, there is increasing importance and demand for efficient development of high quality RSIC systems. The main objective of the proposed project is to establish a platform for a sustained and consistent mobility exchange of graduate students engaged in RSIC oriented programs. These programs will produce graduates capable of working efficiently in multidisciplinary teams engaged in international collaboration on industrial RSIC projects, which require conformance to specific standards mandated by regulatory authorities

Special considerations have to be given to education and training of the technical personnel of the 21st century that will have to operate in an environment that is very complex and technologically advanced. With increasing level of information technologies in industrial processes, the depth of knowledge had to increase too, resulting in distinctive specialization areas. In practice, it is no longer possible to provide an engineering student with all the specialized knowledge s/he might need when entering professional practice using the structure of regular courses of a single educational institution. Therefore, there is a need to propose new solutions for the engineering education to better support distinctive specializations, cross-disciplines and interdisciplinary studies of engineering education. International experts also stress that the engineers of the future would need to have the ability and willingness to learn effective skills in the global business environment and the ability to work in teams.

RSIC systems are often safety-critical, and their dependability is vital to successful operation of the systems. With an abundance of applications interfacing with and controlling the environment, there is increasing importance and demand for efficient development of high quality RSIC systems. The main objective of the proposed project is to establish a platform for a sustained and consistent mobility exchange of graduate students engaged in RSIC oriented programs. These programs need to produce graduates capable of working efficiently in multidisciplinary teams engaged in international collaboration on industrial RSIC projects, which require conformance to specific standards mandated by regulatory authorities.

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(a) Students will be able focus on an area of concentration not available at home institution, due to the opportunity to take classes, get engaged with host institution faculty, the host institution research activities, and access to host institution unique laboratories; and

(b) Students will have a set of experiences related to cultural immersion and to the international aspects of the program.

Acceptance of this proposal, specifically providing funds for student and faculty mobility, will help to create a framework of mobility-based collaboration binding US and EU programs dedicated to the critical mission of educating engineers engaged in design, verification, and operation of dependable software-intensive systems.

These objectives are consistent with the following complementary goals:

- Exploit the mobility exchange mechanism and collect data on its viability.
- Expose students to opportunities of international collaboration.
- Encourage the exchange of staff and students between collaborating institutions.
- To explore the existing multidisciplinary and multicultural experiences of European student exchange system to build a base for transatlantic exchange.
- Provide a forum for the faculty exchange of ideas on the issues of curricula building, laboratory experiments, and assessment activities.
- Enhance English versions of lectures and teaching materials, which are currently supported in Europe.
- Foster a strong technological and education research base.
- Create a foundation to establish fully compatible dual/double degrees.

V. Conclusions

Comparing the IEEE ECBS and ATLANTIS ILERT + DeSIRE[2], we can sum up that while both international initiatives have been focused to the very close engineering areas (RSIC systems appear a sub-domain of CBS), some differences should be outlined:

- ECBS was provided in frame of the IEEE CS Technical Committee and its implementation required additional activities, while ATLANTIS is run by universities that (hopefully) would utilize the developed educational programs.

- ECBS was aimed at multiple single country implementations, while ATLANTIS aims at transatlantic international implementations.
- ECBS considered limited teacher mobility, while ATLANTIS is based on both teachers and students' mobility.

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