ILERT - International Learning Environment for Real-Time Software-Intensive Control Systems

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Abstract:

Due to the heavily software-centric nature of modern reactive and time-critical systems, there is an increasing demand for efficient development of high quality Real-Time Software-Intensive Control systems (RSIC). The study discussed in this paper is focused on the creation of international curriculum framework centred on RSIC this important aspect of computer-system-control-software engineering education. The study explores the mechanism for involving students from multilingual, geographically separated institutions in a coordinated educational experience. It exposes them to the problems, methods, solution techniques, infrastructure, technologies, regulatory issues, and tools in the domain of dependable real-time, safety-critical, software-intensive control systems. The ultimate objective is the creation of a model RSIC curriculum, which can be used by engineering schools both in the USA and the EU.

Keywords: *real-time software Engineering, engineering Curricula.*

1. Introduction

There is an increasing importance and demand for efficient development of high quality Real-Time Software-Intensive Control systems (RSIC). Such systems need to meet stringent safety and reliability requirements and often are developed by companies operating across national boundaries. To educate modern engineers it is critical to establish a methodology for creation of multinational engineering programs, which will produce graduates capable of working efficiently in multidisciplinary teams that are engaged in international collaboration on industrial RSIC projects. Such projects typically require conformance to specific national and international standards mandated by regulatory authorities.

Modern systems are heavily software-centric, implementing reactive and time-critical software, where safety is the major issue and the margin for error is narrow. Examples include aircraft avionics, air traffic control, space shuttle control, medical equipment, and nuclear power stations. It is vital for future software developers to understand basic real-time applications concepts. The area of real-time safety-critical control systems is one of the most advanced and challenging fields of computer science and engineering.

The study discussed in this paper is focused on the creation of an international curriculum framework centred on RSIC. This effort is part of a project on International Learning Environment for Real-Time Software-Intensive Control Systems (ILERT) supported by the European Commission and FIPSE joint EU/USA. The study explores the mechanism for involving students from multilingual, geographically separated institutions in a coordinated educational experience. It will expose students to the problems, methods, solution techniques, infrastructure, technologies, regulatory issues, and tools in the domain of dependable real-time safety-critical software-intensive control systems. The ultimate objective is the creation of a model RSIC curriculum, which can be used by engineering schools both in the USA and the EU. This objective addresses the nations' needs for researchers and developers of real-time safety-critical systems who may be engaged in projects spanning the nations' boundaries and promoting a student-centred, transatlantic dimension to higher education and training.

2. Global aspects of the software industry

International collaboration and globalisation is a key element for the nations to come together in a peaceful way. Creation of common educational experience allows young engineers to find commonalities; it promotes teamwork and collaboration in joint projects crossing the nations' boundaries. Specifically, in the area of RSIC systems used in a regulated industry, it is critical to be familiar with the variety of regulations, standards, and guidelines required for designing, implementing and approving software-intensive systems. The proposed study creates a viable vehicle for such solutions.

There is a clear need to prepare professionals for international collaboration. Understanding critical issues related to RSIC, the tools and techniques used, and documentation required for approval of systems in a regulated industry is critical for the future global projects. The ILERT project is meant to support such international collaboration and consensus building.

3. Curricular issues

There exists well-established guidance for the development of computing curricula [1, 2] and there is a variety of excellent engineering offered in colleges and universities on both sides of the Atlantic. However, at this time, there is no international, interdisciplinary curriculum that directly focuses on real-time control systems, dependable software development, safety, reliability, and the certification issues in highly regulated industries like aerospace, medicine, transportation, and nuclear energy. In addition, there is no curriculum that includes globalisation aspects of the modern engineering profession. The current study will lead to the design of such 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. These objectives are consistent with the following complementary goals:

- Identify a methodology for design and implementation of a transatlantic, multidisciplinary engineering program.
- Stimulate students to follow careers by encouraging them to consider the area of real-time safety-critical control systems and expose them to opportunities of international collaboration.
- Encourage the exchange of staff and students between collaborating institutions.
- Offer multidisciplinary and multicultural experience to students who would not otherwise have such opportunities.
- Provide a forum for faculty exchange of ideas on the issues of curricula building, laboratory experiments, and assessment activities.
- Create a foundation for Internet-based laboratory educational experiences, which will expose students from different countries to tools, methods, and techniques used in the creation of highly dependable safety critical systems for regulated industry.
- Stimulate the teaching staff of the European partners to develop and introduce English versions of lectures and teaching materials.
- Foster a strong technological and education research base.

4. Activities

The two-year study, supported by the US Department of Education Fund for Improvement of Post-Secondary Education (FIPSE) and the EU European Commission, is dedicated to the creation of a unique RSIC curriculum focusing on real-time software-intensive control and safety-critical dependable systems. The ILERT project involves international collaboration of four universities, which allows for exploration of the global implication of offering transferable engineering curricula. The partners include one American and three European universities located in three different EU countries, where English is not the language of instruction (Poland, France, Czech Republic). These partners have adequate educational/research potential; and, through their industry and international outreach, they also recognize the needs of the current and prospective labour market for real-time control education, both in Europe and in the USA. They have published on the issues related to engineering curricula improvement [3-6, 8-10].

A two-pronged approach is used. The first includes active partners' collaboration on identification of the learning objectives and outcomes, description of the curriculum core and supporting units, development of guidelines on the implementation and assessment, identification of the technology infrastructure, and the description of faculty and staff requirements, pedagogy and delivery concepts, accreditation issues and constraints, etc. On-site research by the project faculty and selected students has been enhanced by frequent communications and dedicated working sessions at the partners' sites. The second part of the approach is a practical case study on how the proposed framework can be implemented by the partner institutions. Identification of the existing or easily modifiable courses, which can be used as units in the RSIC curriculum, has been attempted. A description of the laboratory infrastructure, necessary administrative procedures (admission, scheduling, and credit transfer), an assessment methodology, and experimental development and delivery of a selected RSIC unit to partner institutions were undertaken. This experimental concurrent delivery, still in planning stage, will engage on-site students only. The knowledge gained from the experience and relevant observations constitute a base for establishing a dedicated international transatlantic program in Real-Time Software-Intensive Control and may serve as a framework for development of other global engineering curricula.

The project deliverables include:

- Analysis of industry requirements for graduates of the RTSC domain;
- International, interdisciplinary Real-Time Software Intensive Control Systems curriculum framework;
- Design for a selected unit supporting the proposed RSIC curriculum with the draft of lecture materials and laboratory handouts;
- Plan and pilot implementation of a laboratory infrastructure allowing students to actively participate in class activities and experiments on a remote basis;
- Experimental concurrent delivery of the designed unit at the four partner sites;
- Identification of activities and data for program assessment and evaluation, and those issues and elements required to consider program accreditation;
- Reflection on a process and methodology for creation of multidisciplinary, transatlantic engineering programs, including guidelines for extension of the approach to other engineering programs.

5. Analysis of industry requirements

Feedback from future employers of graduates is critical to the design of a curriculum, which fully matches the continuously changing job market demands. A survey was designed to get this feedback from a specific sector of industry regarding what employers expect graduates to have in terms of skills and attitudes, as well as knowledge of technical topics. This Internet based survey was solicited from a representative sample of industry engaged in real-time software-intensive control systems. The collected data were analysed and the results were used to help identify academic program educational outcomes and objectives thus preparing a base for creation of a new curriculum framework.

The respondents reflected an international composition of the ILERT project representing four countries: Czech Republic, France, Poland and USA. It needs to be noted, that we had relatively weak response rate upon the initial e-mail solicitation. The reason was that in many cases the mailing was intercepted by spam filters or the respondents were too busy to commit about 15-20 minutes to fill the survey. Occasionally, the survey reached an individual who was not prepared to provide the requested

Table 1. ILERT Survey Companies.

Country	Company Name
USA (12)	Avidyne, Raytheon, Hawker Beechcraft Corporation, Stuart W. Law Company, Boston Scientific, Teledyne Controls, Boeing, Honeywell Aerospace, Hamilton Sundstrand.
Poland (14)	CSN-STANEL Automatyka, ABB Corporate Research, Astor, Abis, RAControls, InTeCoFEV Polska, Pumpa, Tarbonus, Multiprojekt, Computer Systems for Industry, ComArch, INVENTIA, MPL Technology.
Czech Republic (10)	Tescan, ANF DATA, B+R Automatizace, Honeywell, Freescale Czech Republic, ADC Czech Republic, CAMEA, Flextronics Design, ANeT Ltd., Schneider Electric CZ.
France (7)	CIRTEM, National Research and Safety Institute, ST Microelectronics, IRSN Radioprotection and Nuclear Safety French TSO, Leroy Somer, Airbus S.A., Euro-Systems.

Table 2. Industrial Survey Items.

Part A Items	Part B Items
A.1. Work as a part of a multidisciplinary team	B. 1. Good background in mathematics
A.2. Analyse, understand and define the problem	B. 2. Familiarity with a specific application domain
A.3. Think independently and search for solutions	B. 3. Knowledge of control theory, algorithms and applications
A.4. Make oral presentations	B. 4. Knowledge of system specification and design methods
A.5. Write technical reports and papers	B. 5. Knowledge of hardware design and development concepts, methods and tools
A.6. Communicate with people and present arguments	B. 6. Knowledge of software design and development concepts, methods and tools
A.7. Communicate in a foreign language	B. 7. Knowledge of formal methods applied to system development
A.8. Lead a team	B. 8. Experience with hardware development platforms (e.g. FPGA, PLC, microcontrollers, I/O devices)
A.9. Understand value and cost	B. 9. Knowledge of networking components, topologies and communication protocols
A.10. Experience international, social, cultural and political issues	B. 10. Proficiency in software program construction (programming language)
	B. 11. Understanding the concept of real-time systems (timing, scheduling, RTOS services)
	B. 12. Familiarity with software development tools and development environments (integrated development environment - IDE, compilers/ interpreters, simulators, emulators, code/test generators)
	B. 13. Knowledge of system development process and project management
	B. 14. Experience with hardware/software integration, including testing and verification
	B. 15. Knowledge of quality control, validation, verification, and certification (e.g. for dependable systems)

information. Repeated contacts and follow-ups allowed us to receive enough data to consider the results as valid. Eventually, as a response to over 370 solicitation we received 43 responses (11% response rate). We are grateful for the companies who took part in the survey and provided us with a valuable feedback. The names of companies are listed in Table 1.

The survey, designed by the ILERT project partners, was placed on a web server and participants were invited via e-mail, phone, and personal contact to login to the survey site and provide their responses. The survey included two main categories: Part A and Part B. Part

A was intended to assess the importance of general skills, capabilities and attitudes of engineering school graduates when they enter the job market. Part B included items related to specific technical areas and skills. The items in Part A and Part B are listed in Table 2.

In both, Part A and Part B, the items could be rated as: Essential, Important, Unrelated, and Unimportant, with a possibility to provide comments. In addition to selecting responses in Parts A and B, the survey included Part C, where responders were asked to create a "wish list", i.e. to rank the first three items in each category according to their importance for the need of their company. In Part D, the survey asked respondents to fill information regarding the company profile, size, type of projects, etc. This information was treated confidentially to be used only to analyse and create aggregated results.

A detailed analysis of the results is contained in [7]. Figure 1 depicts the relative ranking of the importance of the Part A Survey items. The highest scores received items related to understanding, problems solving, creativity and teamwork. The responses underscore the need for employees capable of communicating and using modern technologies. Figure 2 shows the ranking for the Part B Survey items. The highest score received items related to knowledge of methods and techniques related to software and system design and development. The responses underscore the industry need for employees that could be efficient from day one when facing new project and adapting to new development environment.

6. Educational objectives and outcomes

The industrial survey results verified the generally agreed upon set of non-technical skills and behaviours expected from engineering school graduates (oral and written communications, professional ethics, team skills, etc.). More importantly, the survey provided a starting point for designing a specific program curriculum by helping the ILERT investigators to identify the technical knowledge areas and skills required from graduating students. Discussion and analysis of the survey results led to the definition of a general set of RSIC program educational objectives and outcomes, defined in terms of the expected graduates' proficiency, specifying the profile of graduates and their competencies. We used the definitions of Program Educational Objectives (PEO) and Program Outcomes provided by the Accreditation Board of Engineering Technology (ABET). PEO are broad statements that describe the career and professional accomplishments that the program is preparing graduates to achieve. PO are narrower statements that describe what students are expected to know and be able to do by the time of graduation.

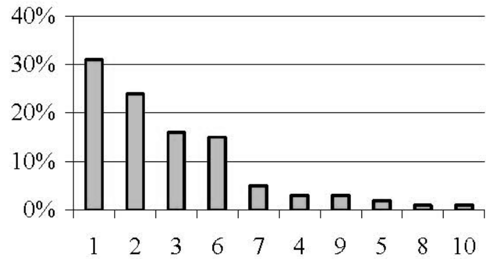

Fig. 1. Ranking of Part A Items.

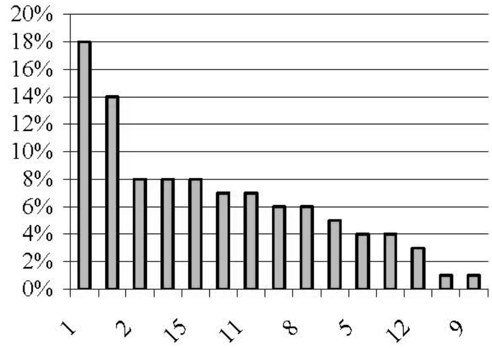

Fig. 2. Ranking of Part B Items.

The graduates of any high quality-engineering program are expected to meet the following general four program educational objectives [A-D]:

[A] Demonstrate professionalism in their work and grow professionally through continued learning and involvement in professional activities.

[B] Contribute to society by behaving ethically and responsibly, and by incorporating knowledge of history and culture into one's professional decisions.

[C] Communicate effectively in oral, written, and newly developing modes and media.

[D] Assume a variety of roles in teams of diverse membership.

The major areas of proficiency for the graduates of an international RSIC program (3-4 years of university/college education) have been identified based on the results of industry surveys and discussion at the consortium meetings. These areas expand the general objectives with three additional [E-G] specific to the RSIC program:

[E] Demonstrate understanding of analysis and design as applied to modern software-intensive control systems.

[F] Demonstrate understanding of processes and techniques and the role of modern engineering tools necessary to engineering practice as applied for creation of software-intensive systems.

[G] Demonstrate understanding of quality assurance and hardware/software integration for creation of safe and dependable systems.

The Program Outcomes are characteristics of the graduating students that can be evaluated at the program completion. They include ability to:

1. … apply knowledge of mathematics, science, and engineering to solve technical problems;
2. … design and conduct experiments, and an ability to analyse the data;
3. … Analyse and understand the operation of a control system or component to meet desired needs (feedback, stability, system dynamics, robustness);
4. … apply advanced software engineering techniques to implement real-time concepts (timing, scheduling, concurrency, synchronization);
5. … support assurance of the quality of a software-intensive system across its lifecycle including

assurance of its dependability using established standards and guidelines (verification, validation, testing, safety, reliability, security, standards, guidelines);
6. … integrate hardware and software on variety of platforms with various interfaces and protocols;
7. … use a defined lifecycle process in development of software-intensive system;
8. … function on multi-disciplinary teams;
9. … understand professional and ethical responsibility;
10. … communicate effectively;
11. … work effectively in an international environment;
12. … understand of the impact of engineering solutions in a global and societal context;
13. … recognize the need for and engage in life-long learning including ability to pursue graduate studies;
14. … understand contemporary issues in software engineering, especially in the RSIC area.

The program outcomes help to identify the topics necessary for preliminary curriculum design. It is critical to understand the role of general education requirements, which complements the engineering facet of the curriculum and facilitates the main objective of university mission: to produce valuable and contributing members of the society.

7. Assessment

Quantitative and qualitative indicators need to be used to assess the degree of fulfilment of the planned objectives and outcomes in the proposed time-frame, based on the detailed plan of work with specific timeline and detailed deliverables. There are three categories of indicators, related to the output, the results, and the impact. The output indicators provide information elaborating the immediate and short-term effects resulting from the planned execution of the project. These include curricula design, educational events, external institutions that have benefited from the project outputs, created artefacts, and presentations shared with external audiences. The results indicators provide information on the project output and the immediate results: new cooperative initiatives, published papers, position documents generated, etc. The impact indicators measure the long-term effects: institutions implementing the proposed framework, learning tools and services created by the project, citations and references to the project documents and papers, third-party references to project outcomes, etc.

Real-time software-intensive safety-critical control systems represent a rather narrow and specific education and research area. Not many courses are offered at the undergraduate and graduate level, since appropriate coverage requires a significant amount of diverse domain knowledge difficult to include in typically overloaded computer science and engineering programs.

8. Conclusions

Nearly all-engineering disciplines have segments engaged in creation of RSIC systems. The systems are implemented worldwide, which requires a well-prepared workforce of scientists and engineers, who can cooperatively address issues in a multi-disciplinary and international fashion. The ILERT project is intended to strengthen international co-operation and the global links in engineering education. An interdisciplinary specialization in RSIC was selected to produce not only a number of educational artefacts in a domain in high demand by industry, but also (what is more important) a process and a methodology for creation of engineering programs with a compatible quality assurance and assessment process. The graduates of such programs will be better prepared to work on projects requiring interdisciplinary and multicultural viewpoints. This enhances mobility of the future workforce and facilitates their advancement and career changes.

The objective of the proposed activity is not only to serve the critical population of safety-critical real-time control system developers, but also to disseminate results and provide guidelines to a broader audience of engineering education faculty. The project will capture the process and methodology used by this multidisciplinary and geographically diverse activity for potential re-use by others. The collected observation and data will provide the base and guidelines for future implementation of complete coordinated multinational engineering programs.

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