Design of computer simulator-based learning modules and assessments for a subject in Control Engineering

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Structured abstract

BACKGROUND
The paper presents the design of simulator-based learning modules and assessments in the context of teaching tough and abstract concepts in control engineering related units to maritime engineering students in the modern era of high technology. Maritime engineering students at the Australian Maritime College, University of Tasmania, have a great challenge in comprehending control engineering units that contain much mathematics related abstract concepts and principles. Good pedagogic methods and practice should be applied in teaching such tough concepts so that maritime engineering students motivate themselves in student centred learning. Computer simulators provide flexible tools to visualise control concepts so that students can comprehend dynamic behaviour of a control system. The paper discusses the author's recent teaching practice in simulator-based learning modules and assessments and investigates their efficacy in students' learning process.

PURPOSE
The main purpose of this paper is to introduce the design and practice of computer simulator based learning modules and assessments for a control engineering related unit to be taught at the Australian Maritime College/National Centre for Maritime Engineering and Hydrodynamics.

DESIGN/METHOD
The simulator-based learning modules and assessments for a control engineering based unit were designed based on a combination of mathematical models, simulation technique, user interface and visualisation and flexible tools for online and on-campus delivery. A trial using these learning modules and assessments has been done as an assessment component of the control engineering related unit for two years. The efficacy of the simulator-based learning modules and assessments has been analysed by students' involvement in the learning process and feedback/comments.

RESULTS
The computer simulators helped to visualise many tough and abstract concepts of the control engineering related unit and the simulator-based learning modules got students actively involved in learning process and assessments. The method of using simulator-based learning modules and assessments stimulates students' learning motivation and the student centred learning process. All students who took the unit with a simulator-based assessment component were involved in learning process and the majority of students' feedback and comments have been positive.

CONCLUSIONS
The main benefit of computer simulator-based learning modules and assessments is that students can comprehend tough concepts through graphics and animation in the simulators. In comparison with the classic teaching method, the new method has motivated the students' learning and got students involved in student centred learning process.

KEYWORDS
Control engineering education, simulator based learning modules and assessments, criterion-reference assessment

Introduction

Computer simulation is a method to visualise abstract concepts and help students to cognise such concepts more easily and efficiently. Nowadays e-learning or online learning modes are gradually replacing a traditional learning mode. E-learning requires different learning resources that students can access through the Internet or software installed in their computers. Simulation-based learning and assessment are appropriate for both online learning and traditional learning.

Simulations have been used for training and educational purposes over many years. According to Lateef (2010), simulation is a technique for practice and learning that can be applied to various disciplines and types of trainees. With the aid of computers, software and electronics simulation can be done in different ways, from numerical solutions and graphical visualization in computers to hardware-in-the-loop simulations, from a simple system like a mass spring damper system to a very complicated system like a full mission ship manoeuvring simulator for ocean-going vessels. Figure 1 shows the full mission ship manoeuvring simulator for seafarer training courses at the AMC. The ship manoeuvring simulator helps to train seafarer students without operating a real vessel.

Figure 1: Ship manoeuvring simulator for navigation courses at the AMC

Bell et al. (2008) stated that simulation-based training provides innovative and flexible training solutions and mentioned four key categories of distributed learning system features including content, immersion, interactivity and communication, that can be delivered by distributed learning technologies (CD-ROM, simulations) and used to create a desired instructional experience. They concluded that simulations have great potential as a medium to create highly relevant training contexts where trainees are active participants in the learning process. If these features are applied in simulation-based learning modules for control education then learners will get richness of information or experience.

Stefanovic et al. (2009) developed computer simulation for LabVIEW-based remote laboratory experiments for control engineering education. Their LabVIEW-based remote laboratory included the same educational goals and tasks as normal laboratory exercises. The remote laboratory has a benefit of remote access and 24 hour/7 day availability such that students can use it at their own learning pace.

Chen et al. (2011) developed simulation-based learning modules for electronics with efficacy. Each of the simulation-based learning modules contains three phases: simulative manipulation, concept clarification and concept learning. The simulation-based learning modules, with visualisation, help students to achieve a higher level of cognition by facilitating their interactions with multiple external representations. Students also reflect on phenomena, as observed when learning a given abstract concept. Moreover, visualised learning also

motivates learners and helps them to transfer concepts into long-term memory (Chen et al., 2009 and thereafter references).

Tiwari and Singh (2011) developed an Internet-based remote laboratory with virtualisation of engineering discipline experiments. Their Internet-based remote laboratory is flexible using numerical solutions of simulation programs in combination with the measured data. It can work with both real external devices and mathematical model based simulators. Their Internet-based remote laboratory was developed using LabVIEW, which allows friendly user interfaces with virtual instruments to be designed. They concluded that the Internet-based remote laboratory with virtualisation as the most effective way to deploy the virtual experiments provides the most effective practical experience of the theoretical concepts. The Internet-based remote laboratory is more easily accessible in the era when the high-speed wireless (Wifi) Internet connection is available everywhere.

When becoming a lecturer in the marine control engineering at the Australian Maritime College the author recognised the challenge in teaching tough concepts in the area of automatic control engineering to students. An automatic control system often consists of many components and involves signal processing in which a signal is converted from one form to many other forms. Students experienced difficulty in understanding mathematically based concepts in design and analysis of dynamic systems and controllers. In control theories, a simplified control system in which signal conditioning devices are omitted is different from that in the real world. When solving control problems a student often derives a mathematical model in the form of a differential equation for a dynamic system (plant or process) then determines a solution in order to learn its dynamic behaviour and design a controller with control gains or control design parameters. When control gains change in value, the resulting control system changes its differential equation, so it is hard to solve such a differential equation when changing control gains many times. Derivation of differential equations and solving those equations can be tedious.

Around the world there are many courses related to automatic control engineering. The real labs with experimental equipment are good for students, but it is a great challenge to organise lab sessions for a large number of students within a limited period. Many lecturers are developing virtual labs in various forms such as Java animation, web-based simulators and GUI programs. NI (2011) provided a tutorial for teaching concepts which are typically difficult to understand using LabVIEW in which control design steps are visualised by block diagrams. System responses to different inputs are displayed by both virtual instruments and waveform charts. LabVIEW tools inspired the author to develop a series of simulation programs for the unit "Instrumentation and Process Control" that has been being offered at the AMC. Figure 2 shows a sample simulator program, with GUI, for one learning module related to a level control system with a PID (Proportional, Integral and Derivative) control law.

Distance (off-campus, online) education has become common and practical in many engineering disciplines where real labs are not suitable for online delivery. Web-based and virtual (software-based) labs can be ideally used instead. AMC has been encouraging staff to develop web-based e-learning resources. The author was granted a small fund for an e-initiative project to develop computer simulation programs for education and research in the area of marine instrumentation and control engineering at the AMC.

Education and training in automatic control engineering is related to teaching control theories from fundamental to advanced theory, operation of automatic control systems, design, implementation, installation and configuration of automatic control systems like process control, motion control and robots. Nowadays, due to the availability of high performance computer-aided simulation tools for design and analysis of control systems, control problems can be solved by software programs. Therefore, the author has developed computer simulation for visualization of tough concepts related to control systems. He uses these computer simulation programs to explain technical terms in control engineering and illustrate tough concepts with graphs. The ideas were inspired by current literature on the usage of

National Instruments' LabVIEW programming language to develop simulation tools for engineering education and training, such as Haugen (2013), Ertugrul (2000), Salzmann et al. (2000), Cruz and Gutiérrez (2010), NI (2011), Mogal and Warke (2013) and Sharif (2012).

Figure 2: Sample simulator program

Information technology can be applied educationally to make lectures more attractive to students and motivate student-centred learning. Text and speech (audio) are often less attractive to students when conveying mathematically tough concepts. Biggs (2003) pointed out that visual aids help in the understanding of abstract concepts much more than audio aids and added that educational technology (ET), not the information technology (IT), has great potential in help lecturers reach educational aims and objectives: in managing learning, in assessing learning and in enabling off-campus learning. Harnessing technology helps teaching be more effective.

Control theories are well understood by a deep learning student, but hardly understood by a surface learning student. A virtual lab that visualizes tough concepts may help to motivate a surface learning student. This paper sets out to discuss the following:

- Why simulation should be used in control engineering education;

- How to explain touch concepts by simulation;

- Design of computer simulation based learning modules and assessments for education and training in the areas of control engineering; and

- Usage of computer simulation programs in online and off-line delivery and simulation-based assessment.

Methods and Procedures

In order to develop simulator-based learning modules and assessments a series of simulation programs for instrumentation and control systems have been made using mathematical models. The simulated systems are based on the units' contents. With simulation tools like LabVIEW and Simulink block diagram algorithms were developed to solve ordinary differential equations and visualise solutions in simulation programs. LabVIEW

has been used to develop simulation programs as it has richness of virtual instruments, dynamic simulation and visualisation tools. This section will discuss simulator development and design of simulator-based learning modules and assessment components.

Development of Computer Simulators

The unit related to control engineering that the author is lecturing consists of common sensors and controllers used in the maritime sectors. The simulation programs for this unit include:

- Flow sensors; flow on-off and PID control systems;
- Temperature sensors; temperature on-off and PID control systems;
- Level sensors; level on-off and PID control systems;
- Pressure sensors; pressure on-off and PID control systems; and
- Motor control systems.

In development of computer simulation, mathematical models in the form of differential equations governing the system dynamics, simulation technique to solve the differential equation and software to visualise numerical solutions are required. A simulation program based on a complete set of differential equations to describe the system behaviour (dynamics) include:

- Model parameters, the numerical constants that do not change over the course of the simulation;
- Initial conditions that are important to determine the solution of ODEs;
- Inputs, that are test signals for the system;
- Outputs, that are the simulated results in the form of time history of output variables; and
- Simulation solution control parameters that define the values and choices made by the designer/engineer of the simulation tool, for examples, step size, output interval, error tolerance, and choice of numerical integration.

A simulation program has been developed for each learning module and assessment based on the structure shown in Figure 3. The simulation program, in the form of software, includes a user interface and visualisation unit (using virtual instruments from LabVIEW) and a mathematical models and simulation technique unit. A flexible delivery tool links the user interface and visualisation unit and mathematical models and simulation technique unit to learning module and assessment components for the module. A flexible tool can be MyLO, website, a CD-ROM or USB memory stick with pdf documents and simulation programs. Each learning module aligns to the module learning outcomes and with the unit's learning outcomes.
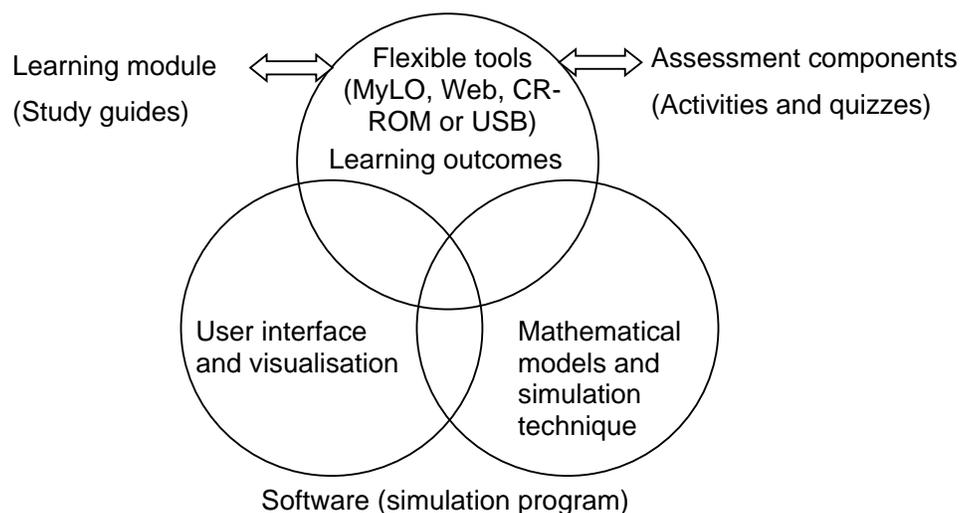

Figure 3: Interactions between the simulators (programs), learning modules and assessment components

The simulation programs have been designed such that they are flexible to change when the learning module contents are changed. Each learning module has some simulated scenarios on which it focuses. The assessment components will change according to the learning module contents. A dc motor control system is described below as an example of a typical learning module.

The dc motor control system simulator includes the following components:

- Mathematical models for plant/process (a dc motor system), measurement element (tacho or encoder) and filter/observer, PID controller and an actuator;
- User interface components and block diagrams; and
- Modes: open-loop (manual) mode and closed-loop (automatic) mode.

In order to enhance performance of a control system, as it operates in a real world, a random noise function can be added to a simulator. The outcomes of a simulation program are visualised and displayed by dynamic simulation tools in LabVIEW.

The tough concepts such as test input signals (reference signal), the transfer function of each component, block diagram, and system responses are shown in a simulation program. Figure 4 shows a user interface (Front Panel Window) of the dc motor control system simulator. The simulation program allows students to collect data for analysis of the system performance and report writing. When a simulator is operated, a test signal (set-point or reference), the corresponding system response, input and output of any component of the simulated system are visualised and displayed.

Figure 4: DC motor control system simulator

Hardware-in-the-loop (HIL) Simulator and Prototypes

It is useful to add an external device into a control loop of a simulation program so that a hardware-in-the-loop simulator is made. A HIL simulator will visualise effects of control actions well. Thus, students can comprehend tough concepts of an automatic control system with visual data. A computer-based HIL simulator as shown in Figure 5 requires a data acquisition card and user interface software.
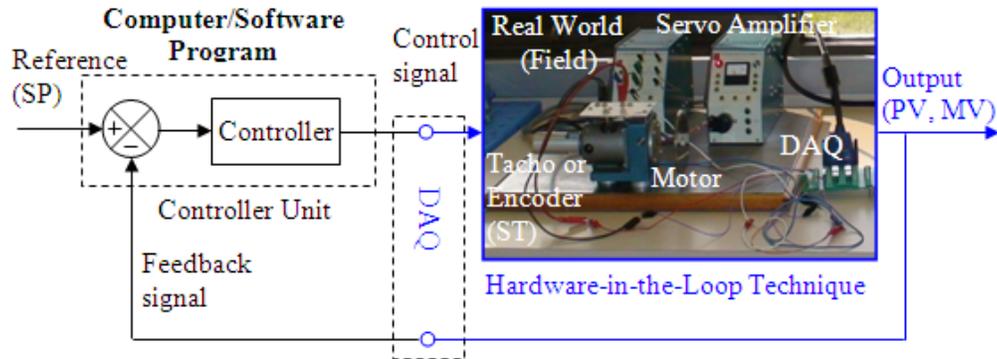

Figure 5: HIL simulation structure

In order to enhance simulator-based learning modules, a simulator can be developed by combining a mathematical model based simulator and an HIL simulator. Object-oriented and graphical programming languages allow the developer to make control programs that can combine mathematical model-based simulator and hardware-in-the-loop simulator for demonstration in classrooms (without external devices) and in laboratories (with external devices). Figure 6 shows a combination of a mathematical model-based simulator and an HIL simulator. The mathematical model based simulators can be used in the classroom to demonstrate tough concepts for students while the HIL simulators are used in real labs for experiments.
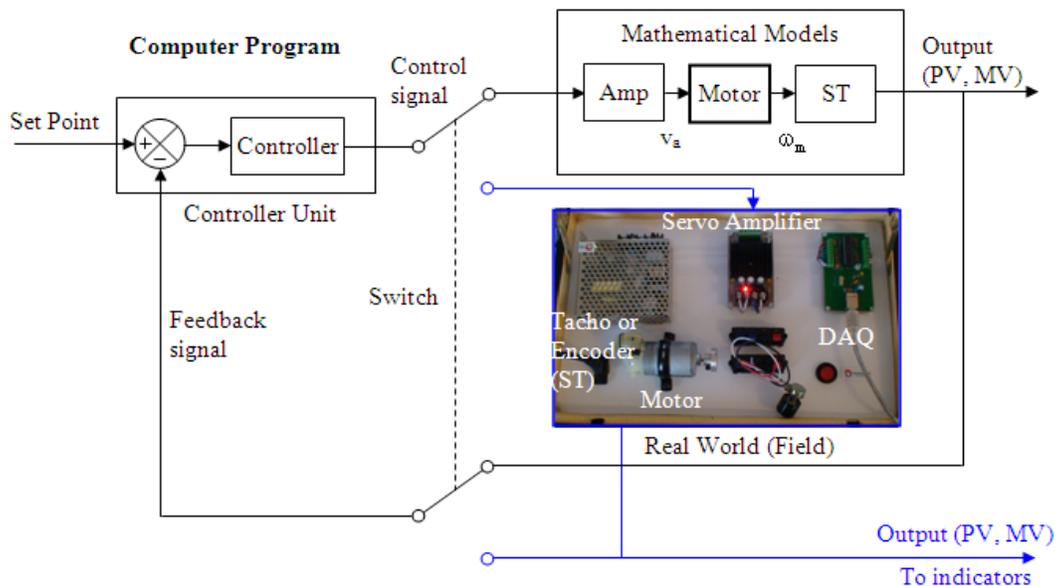
Figure 6: Combination of a mathematical model-based simulator and hardware-in-the-loop simulator using a switch (in the software program)

Simulator-based Learning Modules and Assessment Components

According to Keller (2000), using attractive simulations students can efficiently acquire a lot of experience in controller tuning and suitable tasks include designing fuzzy controllers or tuning PID controller in various control structures. He added that simulation experience would be transferable to real-life problems.

A simulator-based learning module is designed in the following components:
- Instructions to download and install simulator software;
- Instructions to complete the activities; and
- Assessment components (tasks and quizzes).

Haugen (2013) developed a series of LabVIEW based SimView simulators and learning modules for his control engineering related units. His SimVIEW simulators visualised many tough concepts of control systems. The author has developed his ideas further within the context of IT-based education technology. In each simulator-based learning module and assessment, the document consists of the following information:
- Learning outcomes;
- Description of the simulated system with a snapshot of the simulation program (Front Panel Window);
- Aim;
- Motivation;
- Mathematical models;
- Tasks and activities; and
- Quizzes.

Learning outcomes: the learning outcomes of each simulator-based learning module are aligned with the learning outcomes and assessable components of the unit. The learning outcomes are specified within the learning module and the achievement is assessed by quizzes.

Description of the simulated system with a snapshot of the simulation program: describes the simulated system and its components, signal processing within the system and its features. A snapshot of the simulation program is provided to further explain the simulation program.

Aim of the learning module: states the main aims of the simulator and learning modules.

Motivation: states the motivation of the simulated system and learning module. This helps students to focus on their learning.

Mathematical models: provides the relevant theory related to the simulated system, the mathematical models for all components used in the simulator. These models help students to have deep learning on the simulated system.

Tasks and activities: provide students with instructions/user manual on how to operate the simulator in the context of the predefined scenarios in order for students to achieve the above-mentioned learning outcomes.

Quizzes: are assessable components. After doing the tasks students understand the simulator and its scenarios, and they can answer the quizzes. The number of quizzes and their difficulty levels depend on how deep the required knowledge and skills are and the weight of the assessment components.

As a trial, simulator-based learning modules include assessment components weighing 10% of the unit marks. When delivering lectures related to each simulator, a lecturer spends about 10 to 15 minutes demonstrating and explaining how to use the corresponding simulator. The assessments are criteria-referenced, with a set of criteria and grading rubric for each assessment component set out in alignment with the unit and module learning outcomes. Some features of the criteria-referenced assessment (CRA) are knowledge conceived as expressed in the objectives; usually assessed qualitatively; assessment tasks are contextualised for assessing functioning knowledge and decontextualised for assessing

declarative knowledge; reporting in qualitative categories; and aspects of assessment can be teacher-controller, peer-controlled or self-controlled as suits the task to be learned (Biggs, 2003).

In addition, each learning module has student feedback/comments on the simulator, tasks, and students' experience in using the simulator-based learning. The student feedback and comments help to improve the module and assessment for future.

Feedback from Students

As a trial delivery, the above-mentioned simulator-based learning modules and assessments have been used as an assessment component weighing 10% of the unit marks over two years. As mentioned above, each simulator-based learning module has feedback/comments. Over two years about half of students provided their feedback/comments on the learning module and assessments. The majority of the feedback and comments were positive. There is no data available on the ratio of positive to negative feedback/comments. The following are some of the positive feedback/comments:

- *It was a very good exercise and easy for students to understand the flow of work.*
- *The simulators helped me to understand the theory very much.*
- *I like the simulators and quizzes because they are interesting and the quizzes are quite straightforward.*
- *I wish that the weight of the simulator-based assessment would be larger.*

The simulator-based assessments (10%) were conducted in 2012 and 2013. In 2012 there were 38 students, 100% students completed the assessments and results were HD (80-100%): 66%, DN (70-79%): 32%, CR (60-69%): 0%, PP (50-59%): 0% and < 50%: 2%. In 2013, there were 25 students and only two students did not complete. 2013's results were HD (80-100%): 60%, DN (70-79%): 24%, CR (60-69%): 4%, PP (50-59%): 0% and < 50% (two did not complete): 8%. The results were higher than that of other assessments.

In the following years the simulator-based learning modules and assessments will be re-designed with an increased weight and well-organised feedback/comments so that more feedback and comments are provided by the students.

Conclusions

The paper has discussed the design of simulator-based learning modules and assessments for a control engineering related unit taught at the AMC/UTAS. The simulator-based learning modules and assessments helped to motivate students in a student-centred learning process. A simulator-based learning module with criterion-referenced assessments was created by three units: user interface and visualisation unit, mathematical models and simulation technique unit and flexible tools unit. The simulators with a friendly user interface help to explain tough concepts of control systems. The main benefit of computer simulator-based learning modules and assessments is that students can comprehend tough concepts through graphics and animation in the simulators. In comparison with the classic teaching method, the new method has motivated the students' learning and enhanced in a student centred learning process.

In future simulators for more complicated dynamic systems, such as surface vessels and underwater vehicles, training and education will be developed using virtual reality technique by which students can capture how a dynamic system works and observe responses to any change in an input/set-point signal.

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