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Benchtop-based hardware with simulation for laboratory-based learning in an electronics control system course using spreadsheet programming

Andriani Parastiwi, Ekojono, Cahya Rahmad & Anugrah N. Rahmanto

State Polytechnic of Malang
Malang, Indonesia

ABSTRACT: In teaching laboratory-based courses, consumable materials and equipment are necessary. The required consumable materials and equipment makes engineering education into an expensive form of education with higher tuition fees than social education. Therefore, the lower the budget for consumable materials and equipment, the cheaper will be the tuition fees. Present laboratory experimental equipment to teach control systems for electronics engineering students can be acquired at a lower cost than by buying ready-to-use equipment. Benchtop hardware consists of a circuit used to provide students with low-cost, practical hardware, while simulation using spreadsheets is used to model the system, which includes theoretical prediction and non-ideal features of the control system.

INTRODUCTION

In engineering education, freshmen usually enter the university in a certain field of interest and expect to become professionals upon graduation. The university has developed an excellent curriculum to response the expectations, but this leaves the lecturer with great responsibilities for implementing the curriculum through the courses. Lecturers use a pedagogical approach to guide students, so they learn how to become a professional in almost all courses. In pedagogy, students are very dependent on the lecturer, whereas the lecturer assumes himself/herself that he/she is fully responsible for what will be taught and how to teach it, as well as how to evaluate learning outcomes. Other considerations, such as the complexity of the newest technology and diversity in technology applications in society call for a new approach to undergraduate engineering education [1].

In engineering education, there is usually a lecturer in the classroom, whereas some courses are done in laboratories. Teaching laboratory-based courses has been shown to facilitate better student-faculty interaction through research projects serving better academic achievement and student retention [2]. In addition, study programme accreditation has forced the institutions to meet certain minimum standards that have an impact on how the lecturers have to teach the course [3][4]. Therefore, the lecturer has to design a certain pedagogical approach suitable in his/her classroom-based courses, as well as in the laboratory-based courses.

In teaching laboratory-based courses, consumable materials and equipment are necessary. The required consumable materials and equipment make the engineering education expensive, with higher tuition fees than social education. Therefore, the lower the budget for consumable materials and equipment, the cheaper the tuition fee will be. Rodriguez used LabVIEW on a computer-based system to permit students to use low-cost hardware [5], whereas Goodwin used a low-cost emulation-based system to give students an introduction to real-world control engineering design [6]. In this article, the authors present laboratory experimental equipment to teach a motor control system for electronics engineering students, which can be acquired at a lower cost than buying the ready-to-use equipment.

PROBLEMS IN THE LABORATORY-BASED LEARNING APPROACH IN ELECTRONICS ENGINEERING COURSES

The engineering curriculum provides lectures supported by laboratory work. However, this leads to a major dilemma for educational institutions; namely, how to achieve the right trade-off between the cost and the provision of practice in education. This is a dilemma for engineers and educational researchers around the world. How have accreditation bodies, economic pressures, and the emergence of new technologies as the inspiration for the creation of new systems to create new laboratories in education influenced the pedagogical approach? Which model of learning should an educator choose? In this case, some models of learning are proposed and suggested as an alternative suitable for the situation and conditions faced in teaching in electronics engineering, as seen in Table 1.

Table 1: Learning model for electronics engineering courses.

	Lecture-based learning	Case-based learning	Problem-based learning	Laboratory-based learning
Type of problem	Example	Scenario	Occurrence	Real life
Why to use?	To receive information from the lecturer and to memorise the content	To provide students with a relevant opportunity to see theory in practice	To integrate knowledge and skills from a number of disciplines	To provide training in observation, supply detailed information, and arouse students' interest
Role of lecturer	Resources	Facilitator	Facilitator	Expert
Role of students	Listening	Analyse data to reach a conclusion	Exploring solution	Following guidance
Expected result	Learning result	Learning result	Learning result	Learning result
Assessment	Individual	Individual	Individual	Individual
Time per problem	1 hour or more	1 week	1 or 2 weeks	1 week

The first model of learning is lecture-based learning. Knowledge that is information and procedural that leads to basic skills will be more effective, if delivered by way of lecture-based learning. Lecture-based learning is often referred to as a lecture or expository method, and it prepares students by serving information and procedures, guided training, reflection, self-training and evaluation. In lecture-based learning, students receive information solely from the lecturer and attempt to memorise the content instead of understanding the concepts and using them. Students usually perform reasonably well when simple problems are presented to them. However, when the face new situations they are less responsive, and do not try to think of finding new steps in solutions that would resolve the situation [7].

The second learning model is case-based learning through which students are engaged in discussion of specific scenarios that resemble or are typically real-world examples. This method is learner-centred with intense interaction between participants as they build their knowledge and work together as a group to examine the case. The instructor is the facilitator, while the students analyse and address problems and resolve questions. This case-based learning method provides …*students with a relevant opportunity to see theory in practice.* Real world or authentic contexts expose students to viewpoints from multiple sources and see why people may arrive at different outcomes [8]. With this learning model, the students will understand the process and the effect of their decision on others, both positive or negative [8].

The third learning model is problem-based learning (PBL), this model trains and develops the ability to solve problems that are oriented to authentic problems in the student's actual life, to stimulate higher-order thinking skills. Conditions that are maintained is a conducive atmosphere. It is open, negotiating, democratic, comfortable and a pleasant atmosphere for students to think optimally. Indicators of this learning model are metacognitive, elaboration (analysis), interpretation, induction, identification, investigation, exploration, conjecture, synthesis, generalisation and inquiry. Problem-based learning is one of the most commonly used educational methods in engineering education. In this method, students use scenarios to define their own learning objectives. The problems are the starting point for learning in PBL. Students can become more creative when looking at the problem, and innovation is inspired through knowledge and skills gained during the work of solving the problem. In this way the skills and knowledge to become a professional can be grown [7].

The fourth learning model is laboratory-based learning. In this laboratory-based learning model, developing and teaching an effective laboratory requires skill, creativity and hard work [9][10]. The objectives of a laboratory-based learning are to:

1. deepen the notion of concept;
2. apply the concept of learning in the classroom to a new situation;
3. develop critical and quantitative thinking;
4. develop skills on using scientific tools;
5. develop skills on reporting capabilities (written and oral).

The most important thing that can be done to ensure the laboratory runs smoothly is that it is well prepared. The preparation prior to commencement of the semester should include an equipment list in the laboratory warehouse, so that time will not be lost during the laboratory to find the requisite equipment or materials. In teaching the laboratory, not only is the awareness of the basics of presentation important, but also a greater understanding of how group work fits into the wider context. A good laboratory instructor is a great teacher and a great manager. He/she makes students understand the work that has to be done, tries to experiment and deal with relevant practical issues, and turns experiments into practice. In addition, laboratory instructors should always be alert to potential problems that will be aroused.

During the practicum, the instructor can ask questions aimed at establishing contact with students and helping students to focus more on the practicum. Examples of questions that can be asked: What will you do next? Why did it happen? Are the results as expected? How to measure it? Is there a measurement differences? In addition, students may also ask the instructor questions, no matter how long the instructor has been preparing them. There will always be questions that cause surprise. In this case, the instructor can ask students to find out the answer (especially if it is their responsibility) or can ask other questions of the student: What do you think of finding the answer to that question? Have you looked into the book or tried this? When the laboratory section ends, the instructor may want to assess the instruction's success, as well as students' lessons in the laboratory. The assessment can be done individually in the formal or informal atmosphere.

A lecturer should always combine elements of theory and practice in his/her teaching. Thus, a lecturer in control techniques giving lectures without a strong scientific basis will be superficial and dangerous, and in addition, lectures without reference to practical engineering applications will be abstract and non-motivating. Therefore, a combination of theory and practice is needed in electronics engineering lectures. This has led to an educator in engineering always looking for innovative ways to expose students to trigger the nature of professional practice in their chosen disciplines.

In an engineering curriculum it is necessary to combine theoretical foundations that correspond to a strong emphasis on relevance by applying lecture-based learning model. The basic theory is best served in a structured way that is presented through case examples by implementing a case-based learning model. However, in the electronics control system course, it is desirable for theory to be related to the real world of industry. In addition, practical reinforcement also needs to be linked to the theoretical material, so that student learning can be continuously implemented in an integrated manner.

ELECTRONICS CONTROL SYSTEM COURSE

The electronics control system course is to enhance the knowledge gained from the previous electrical and electronic courses. In this course, students will gain the understanding of the general principles of operations of control system electronics circuits. The purpose of control systems is to present and deliver optimum engine power through an accurate working system to produce the minimum exhaust emissions, efficient fuel use, resulting in optimal driving for all engine working conditions, minimising evaporation, as well as providing a diagnostic system to evaluate the working system and the condition of the peripheral of the supporting device in case of undesirable problems in the system. Electronically controlled machines consist of sensor devices that continuously monitor the working conditions of the machine.

An electronic control unit works to evaluate input data from various engine-mounted sensors. By comparing data on its memory and performing accurate calculations, the electronics control unit activates the devices drive as an actuator to produce a good machine working system. The sensor measures various signals in the system and the operator gives commands to the processor to process the measured signal and move the actuator that changes the system condition. Figure 1 shows a wide range of control systems; controlled systems can be a power plant, distribution system, and so on.

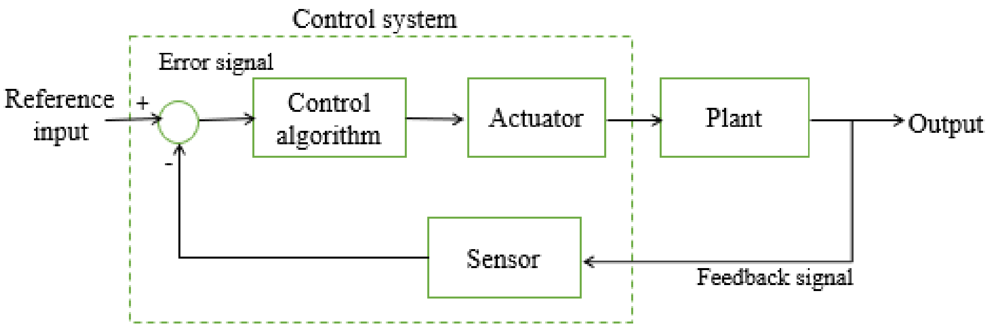

Figure 1: Electronics control system block diagram.

The controller inputs, called a set point, are the reference input and the plant output signal measured by sensor is used as feedback. The controller output is the actuator signal that drives the plant. The control system can represent the control algorithm as simple as a constant value that multiplies the block input or as complex as a nonlinear mathematical representation. It is possible to manipulate block diagrams containing only linear components to achieve compact mathematical expressions representing system behaviour. The goal of this manipulation is to determine the system output as a function of its input.

The expression resulting from this exercise is useful in various control system analysis and design procedures. Each block in the diagram represents a linear system expressed in the form of a transfer function. This basic electronics control system block diagram has to be comprehend thoroughly by students in the electronics control system course. In teaching the electronics control system, performance specification and system stability are the most time-consuming topics. The proposed learning model in this electronics control system course is the combination of the lecture-based and laboratory-based learning.

The lecture-based learning model is used at the beginning of the course to give information that will lead to basic knowledge and students attempt to memorise the content and understand the concepts. Whereas laboratory-based learning model is used to give students understanding, the applied electronics control system tries to experiment and raise relevant practical issues, and turn his experiment into practice. There are many ways that lecturers can give students practical experimental experiences, and the proposed method uses benchtop-based hardware with simple simulation software built using spreadsheet.

BENCHTOP-BASED HARDWARE WITH SIMULATION SOFTWARE USING SPREADSHEET

Benchtop hardware consists of a circuit used to provide students with low-cost practical hardware, while the simulation is used to model the system, which includes theoretical prediction and non-ideal features of the control system. Software control system simulation applications are available on the market, such as FluidSIM, Automation Studio, MathLab, and many others. These can be obtained at a high cost with high specifications of computer hardware. Using the software requires a long period of training for a particular plant. Based on these problems, in this study software applications will be designed that are able to simulate a visual control system of electronic circuit that can be used to prove the truth of design of control system before it is developed. Visual simulation is expected to provide simulation results with a view that allows the user to see and feel as though they are doing the practice of creating a control system by the use of spreadsheets.

Outlined is one of the packages available in the electronics control system laboratory as seen in Figure 2. The hardware plant consists of a minimum system of Arduino Uno, motor DCS-30A with L298 driver, LM393 speed sensor, and 12V power supply as seen in Figure 3. The reason for choosing this hardware is that motors are one of the most common actuators used in control systems, and which consume most of the world's electricity. Industry has focused on controlling motors, so that inefficient electricity consumption can be minimised. Once a motor has been selected, the operation and the control for protection of the motor become important. The educational objectives on this benchtop hardware plant are:

1) limitations of single-input–single-output control system;
2) impact of multivariable control algorithm;
3) impact of actuator specification;
4) system stability;
5) performance specification.

Figure 2: Benchtop hardware plant with a simulation software.

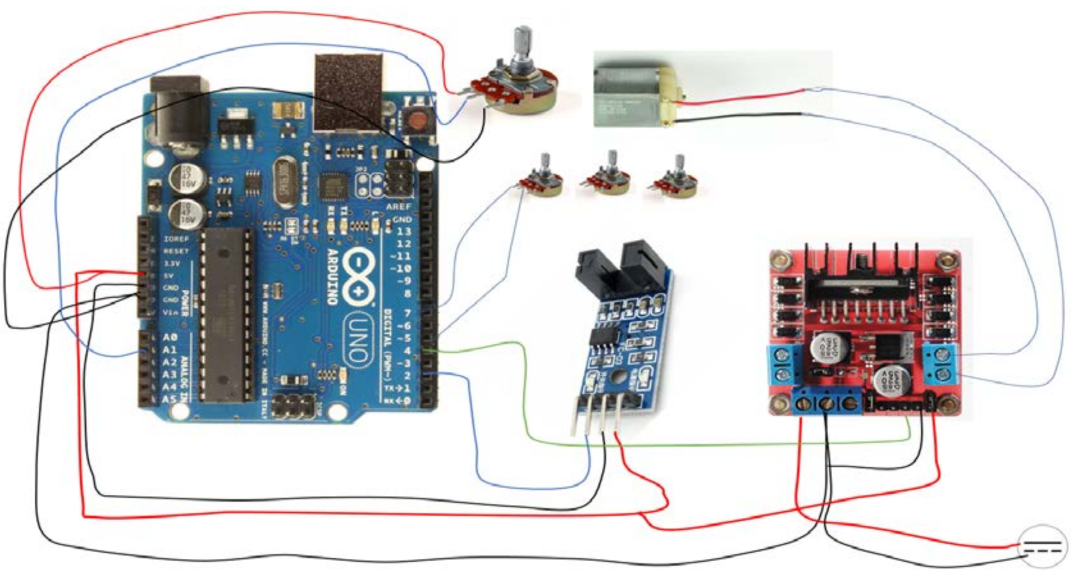

Figure 3: Benchtop hardware block diagram.

Performance specifications are used in the design process to determine when the control design is satisfactory. The performance specifications of the controller can be expressed both in time and frequency domains. The time domain specification is usually related to performance in response to step changes in the input. Whereas the controller reference input is usually a low frequency signal, the noise in the sensor measurement used by the controller often contains high frequency components.

It is normally desirable for the control system to suppress the high frequency components related to sensor noise, while responding to changes in the reference input. Motor DCS-30AE05FA, has a maximum rotation of 6,500 rpm, while the sensor rotation encoder has 20 holes. The wheel passes through the interrupter to create a digital signal read by Arduino Uno. Arduino then reads the motor speed and compares it with the set point given by the potentiometer. Next, Arduino gives orders to the motor driver to adjust the motor input voltage according to the PID algorithm control setting.

Motor speed and set point can be monitored through a personal computer, while students can change PID algorithm control tuning in the PC to get a response. The spreadsheet simulation has been developed to simulate the benchtop hardware in the electronics control system course as seen in Figures 4-6.

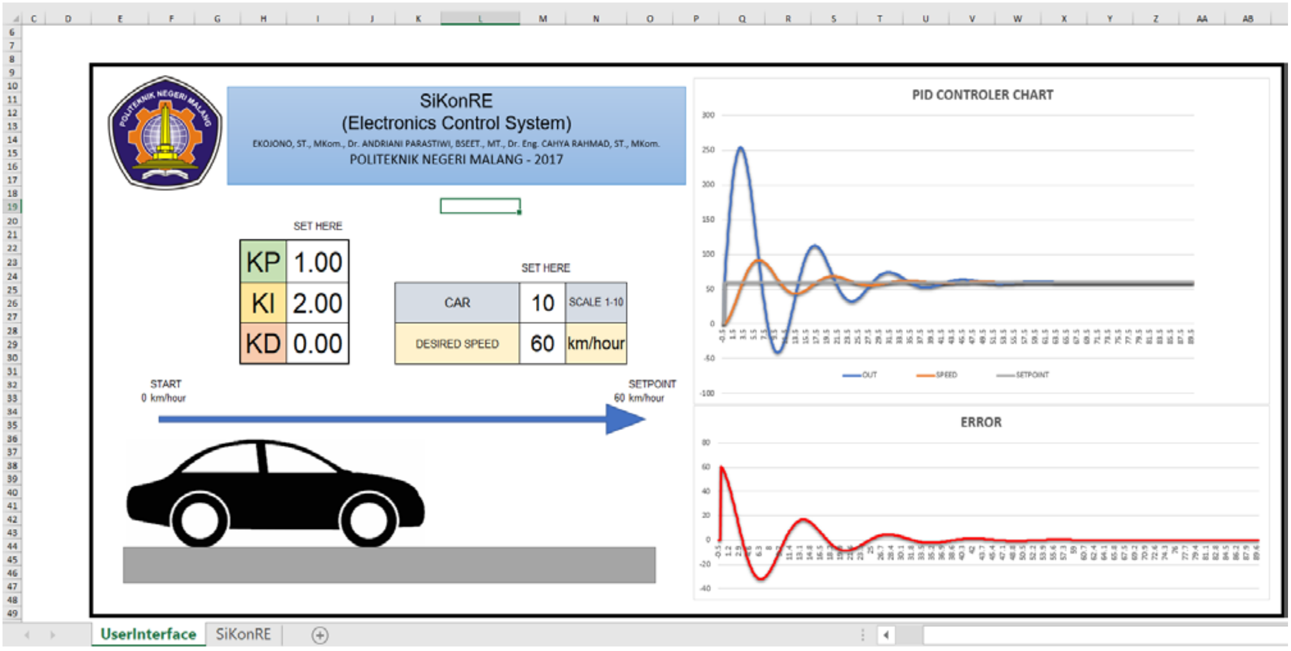

Figure 4: User interface of the benchtop hardware plant simulation.

The parameters that are tuned in the control algorithm are Kp, Ki and Kd. In this control system, the most decisive factor is Ki, because the value of the other value is given a value of 0. The value of zero does not mean the value must be determined due to the other values being zero. Results tuning with the output response indicate that the DC motor takes time for the speed of rotation and can be tuned at the setting point. Figure 5 shows the results of the simulation of the plant without the influence of Ki and Kd where there was only Kp introduced. Figure 6 shows the simulation in the spreadsheet, if Kp, Ki and Kd are added.

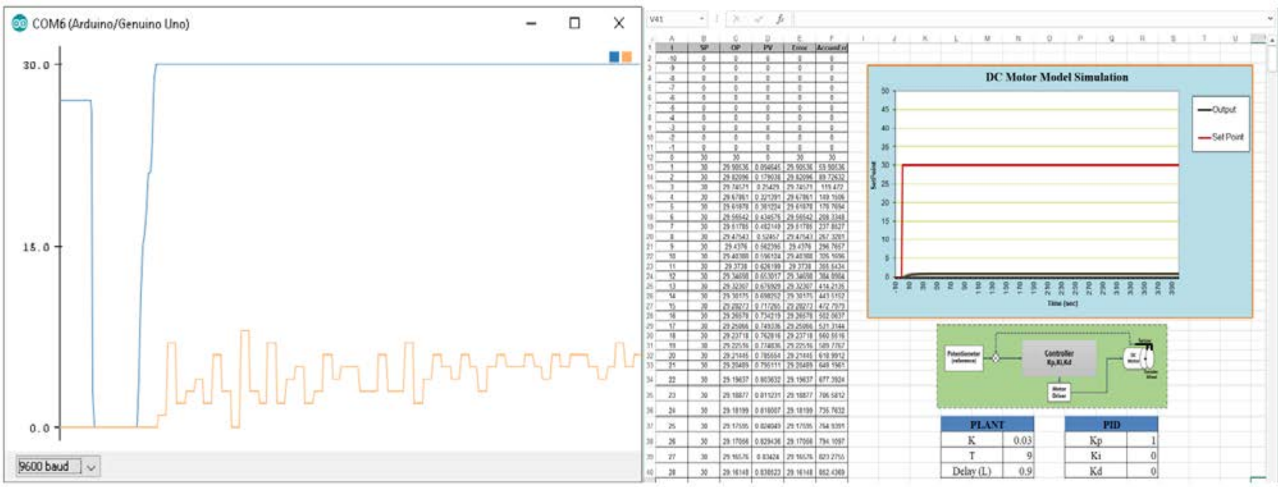

Figure 5: The simulation with only Kp introduced to the PID algorithm.

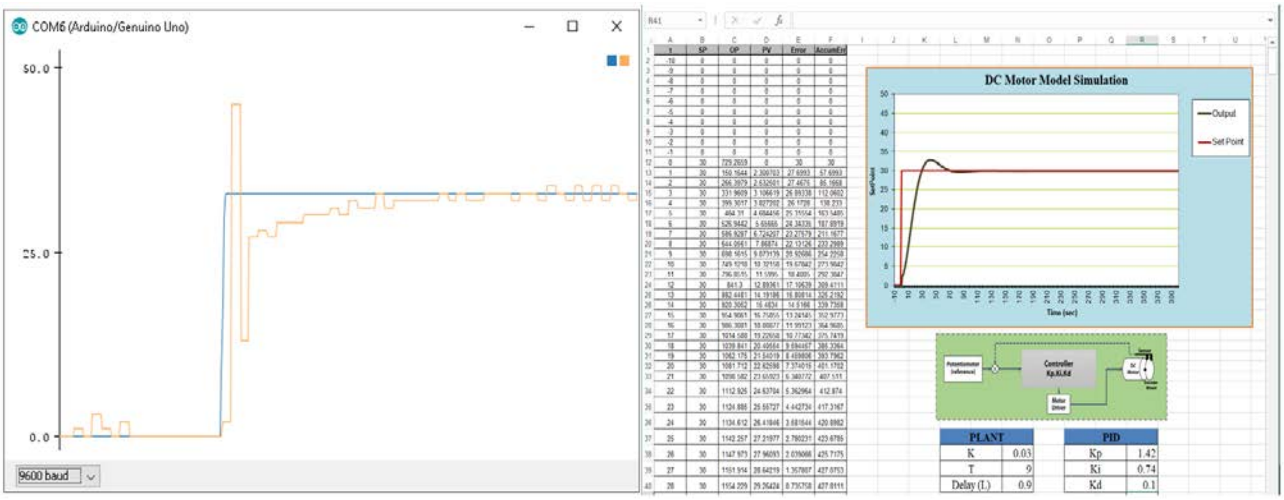

Figure 6: The simulation with PID control algorithm tuning with Kp = 1.42, Ki = 0.74, Kd = 0.3.

CONCLUSIONS

Electronics engineering education is highly dependent on the lecturer for what he/she will teach and how to teach it, as well as how to evaluate learning outcomes. In engineering education, a lecturer gives lectures in the classroom, whereas some courses are done in laboratories. Teaching laboratory-based courses using benchtop hardware plant with a simulation using spreadsheet has been proven to be suitable in teaching electronics control system.

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REFERENCES

1. Kastenberg, W.E., Hauser-Kastenberg, G. and Norris,D., An approach to undergraduate engineering education for the 21st century. *Proc. Frontiers in Educ. Conf.*, 36th Annual IEEE, San Diego, USA, 23-28 (2006).
2. Nagda, B.A., Gregerman, S.R., Jonides, J., von Hippel, W. and Lerner, J.S., Undergraduate student-faculty research partnerships affect student retention. *The Review of Higher Educ.*, 22, **1**, 55-72 (1998).
3. Overton, T., *Key Aspects of Teaching and Learning in Experimental Sciences and Engineering*. A Handbook for Teaching and Learning in Higher Education: Enhancing Academic Practice. eBook. 225-245 (2003).
4. Crosling, G., *Facilitating Student Success*. Improving Student Retention in Higher Education: The Role of Teaching and Learning. eBook, 119-131 (2007).
5. Rodriguez-Resendiz, J., Herrera-Ruiz, G. and Rivas-Araiza, E.A., Adjustable speed drive project for teaching a servo systems course laboratory. *IEEE Trans. on Educ.*, 54, **4**, 657-666 (2011).
6. Goodwin, G.C., Medioli, A.M., Sher, W., Vlacic, L.B. and Welsh, J.S., Emulation-based virtual laboratories: a low-cost alternative to physical experiments in control engineering education. *IEEE Trans. on Educ.*, 54, **1**, 48-55 (2011).
7. McParland, M., Noble, L.M. and Livingston, G., The effectiveness of problem-based learning compared to traditional teaching in undergraduate psychiatry. *Med. Educ.*, 38, **8**, 859-867 (2004).
8. Onyon, C., Problem-based learning: a review of the educational and psychological theory. *Clin. Teach*., 9, **1**, 22-6 (2012).
9. Crosling, G. and Webb, G., *Supporting Student Learning: Case Studies, Experience and Practice from Higher Education*. London: Kogan Page (2002).
10. Feisel, L.D. and Rosa, A.J., The role of the laboratory in undergraduate engineering education. *J. of Engng. Educ.*, 94, **1**, 121-130 (2005).
11. Tan, K.K. and Goh, L.H.. Development of a mobile spreadsheet-based PID control simulation system. *IEEE Trans. on Educ.*, 49, **2**, 28-35 (2006).