

Electronics Courses for Science and Technology Teachers*

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Studying engineering has become less attractive to high school students in Slovenia since the beginning of the 1990s. Faculties of electrical, computer, mechanical and civil engineering faced a drop in the number and/or quality of freshmen students. At the Faculty of Education, University of Ljubljana, we considered that the knowledge and skills of middle and high school teachers of science and technology might contribute to change these trends. To this end, an existing course in electronics for pre-service teachers was modified to emphasize project-based work, integration of science and engineering disciplines, implementation of data acquisition systems, introduction of state-of-the-art topics, etc. The course structure and examples of students' projects are outlined in the paper.

INTRODUCTION

ONE OF THE major prevailing problems in engineering education in Slovenia is that the overall level of knowledge and skills of freshmen students entering engineering faculties has been significantly lower in the last ten years than heretofore. The reason, however, is not a lower level of knowledge of high school students in general, but rather that the total number of candidates currently applying to enter engineering schools is low, so that nearly all candidates who fulfil the formal entry requirements have to be accepted.

The causes of declining enrolment in engineering schools include improved general employment market for graduates, better salaries for graduates in other areas, attitudes to engineering in society at large, etc. This phenomenon seems not to be specific only to Slovenia. To motivate more pre-university students to study engineering disciplines, universities in different (especially technologically developed) countries have found it necessary to organise summer camps, competitions in robotics, after school activities at secondary schools, etc [1–3]. It seems that less effort has been undertaken to improve the knowledge and experience of secondary school teachers on engineering topics. The reason might be that working directly with students gives short-term results while the benefits of working with the teachers is more long-term. University programs that provide vocational qualifications for middle and high schools teachers vary significantly from country to country. But no matter what kind of teacher training program is involved, only a well educated cohort of science and technology teachers with contemporary knowledge in engineering can motivate students, especially the more talented students, to

decide to become engineers. Teachers can influence students' attitudes toward engineering on a more long-term basis compared to the direct involvement of third-level engineering institutions in secondary education. Consequently, the training of science and technology teachers makes a very important contribution to engineering education.

The Department of Physics and Technology, Faculty of Education, University of Ljubljana trains future teachers of physics and technology for middle schools (age of students 12 to 15). If these trainee teachers take some additional courses they can also receive a licence to teach physics at high school level (age of students 15 to 19). The Department also conducts courses for in-service teachers of physics and technology.

In the first two years of pre-graduate study, students of physics and technology education take a standard one-semester course in introductory electronics. This course includes basic digital electronics (logic gates, Boolean algebra, combination circuits) and analog electronics (resistors, capacitors, inductors, diodes, transistors and operational amplifiers). In addition, students of physics take a course on the principles of measurement, which emphasizes the use of sensors interfaced to a multi-function data acquisition system [4–6]. Technology teachers take an electrical engineering course dealing with synchronous, asynchronous, direct current (DC) machines and stepper motors.

It is considered important that lectures be closely related to the laboratory exercises—practical applications of all topics are encountered in laboratory sessions.

INTRODUCTION TO DATA ACQUISITION AND CONTROL

This course has been developed from existing courses on the principles of measurement for

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physics teachers and on robotics for technology teachers. Subsequently, following the introduction of the use of data acquisition systems in chemistry and biology lessons, the course evolved in a more interdisciplinary fashion and oriented towards different levels. The main target groups are secondary science and technology teachers as well as scientists and engineers who are not specialists in the specific topics involved.

The course was developed within the ComLab-SciTech pilot project running under the EU Leonardo da Vinci programme [7]. The final products of the ComLab-SciTech project comprise two novel state-of-the-art data acquisition (DAQ) systems and a range of multimedia courses aimed at different target groups, including school pupils, university students and teachers of science and technology. In parallel a software package, named eProLab, was developed to support the DAQ systems in accordance with the requirements of the courses. The DAQ systems and associated software will presumably be commercially available after the ComLab-SciTech project finishes (end of 2003). Information will be made available on the website [6].

Although the course on Introduction to Data Acquisition and Control involves some fundamental theory, it emphasizes practical hands-on laboratory exercises, the use of the interface with digital input(s)/output(s) and analog input(s)/output(s) such as:

- conversion of decimal and binary records;
- use of digital output for on/off control;
- use of digital output for pulse width modulation;
- use of a photosensor connected to digital input;
- digital input as a stop clock, analog output for light intensity control;
- demonstration of analog input;
- resolution of analog-to-digital conversion;
- calibration of analog sensors, etc.

Instructions for students are written in html format. Hyperlinks are used to run software that supports the use of the data acquisition interface. In the next section below, some examples of such laboratory exercises are outlined.

Digital output as periodic pulse generator

One bit of digital output of the data acquisition interface is connected to an LED in series with a resistor. Initially the frequency of pulses can be selected so that the on/off times are equal. Students are asked to predict at what limiting frequency they believe they would not be able to see pulsation. Most students say that the maximum frequency would be between 10 and 20 Hz. They later observe, however, that the frequency limit is between 40 and 50 Hz. The question related to number of frames per second on a TV screen or in the cinema arises—how is it that we cannot see pulsation there? Then the students are asked to set up pulse width modulation (see Fig. 1). They realize that pulsation cannot be observed, even at 24 Hz, if the LED is on for the most of the time and being off for only a small fraction of the period.

Technology students continue this exercise by connecting a DC motor instead of the LED. They observe that pulse width modulation can be used to control the rotation speed of the shaft. Other exercises, involving eight-bit digital output, include control of rotational direction of one or more DC motors, stepper motor control, etc.

Physics students use the same pulse width modulated LED directed onto a light dependent resistor (LDR). The LDR is connected to a constant current source circuit based on an operational amplifier. Since the voltage across the LDR is proportional to its resistance, students can observe the time response of the LDR and find some analogy with the time response of the human eye. This exercise continues with a comparison of the LDR time response with that of a photodiode and a phototransistor.

'Mechanical' response time of humans

The user interface for the study of human response times is shown in Figure 2. After the white disk on the computer screen is changed (by software) from white to red, the student needs to press a switch (connected between +5V and the digital input of the data acquisition system) as quickly as possible. The time interval in which the white disk becomes red, is generated randomly

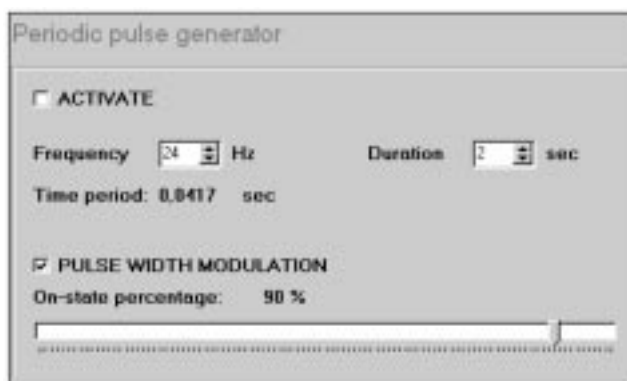


Fig. 1. Exercise with periodic pulse generator using one bit of digital output.

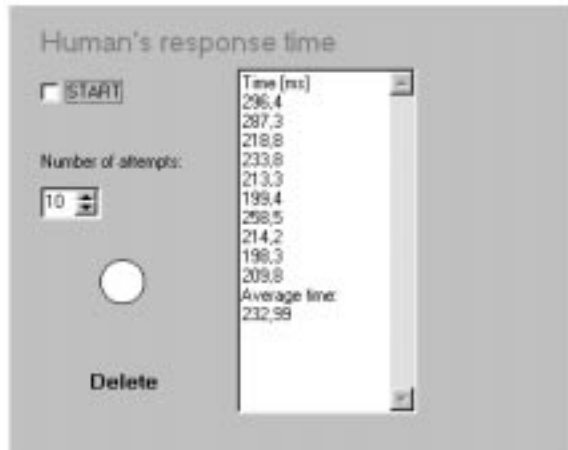


Fig. 2. Computer screen at measurement of human's response time.

between 2s to 6s. After selected number of attempts, an average response time is displayed (see example screen below).

Resolution of analog-to-digital conversion

Students connect a potentiometer to the analog input of the interface. By turning the axle of the potentiometer, a slowly varying voltage may be observed. Students may select different time-bases in seconds per division (sec/DIV) and also the number of bits used for analog-to-digital conversion (from 12-bits to 1-bit, see 4-bit example in Fig. 3).

EXAMPLES OF STUDENT PROJECTS

Project-based work is introduced during the second two years of pre-graduate study for future science and technology teachers. Projects

are evolved from each student's own initiatives. Pre-service and in-service teachers of biology and chemistry are also encouraged to initiate projects. Two such projects are outlined in this section.

Dynamics of biomass growth

Biomass is a term usually mentioned in connection with alternative energy sources. As such it is a good starting point in classes where a number of different science and technology disciplines are closely integrated. But what are the dynamics of the biomass growth and what can influence this? Is it possible to perform an investigation on such topics with limited resources in equipment, time (and knowledge)?

The starting point of the 'research' involved a study of the mass of a flowerpot initially containing just soil and later after some seed (in this case barley) has been added. During the growth of a plant, the mass of the 'flowerpot' is observed to increase compared to a reference flowerpot with just soil and no seed. The next problem was to decide how to supply water continuously to the soil in an attempt to achieve stationary conditions in relation to the amount of the water within the soil. A suggestion by one student, approved by the most of the others, was to supply water to the soil via a length of textile fabric placed at the bottom of the pots and dipped in water at the other side. The resulting apparatus is shown in Fig. 4.

After addressing these general problems, it was time to proceed to the 'engineering' part of the project. Discussions about measurement instrumentation quickly focused on the need for a computerized measurement system, since a measurement frequency of a few times per hour for a duration of more than a week would be required. A force sensor was clearly required to measure the difference in the mass of the control

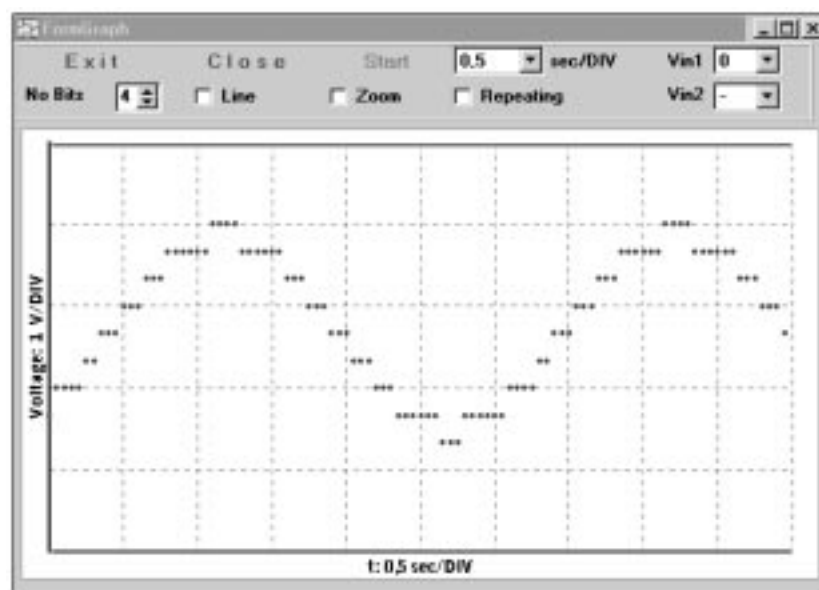


Fig. 3. Signal from potentiometer utilizing 4-bit analog-to-digital conversion.

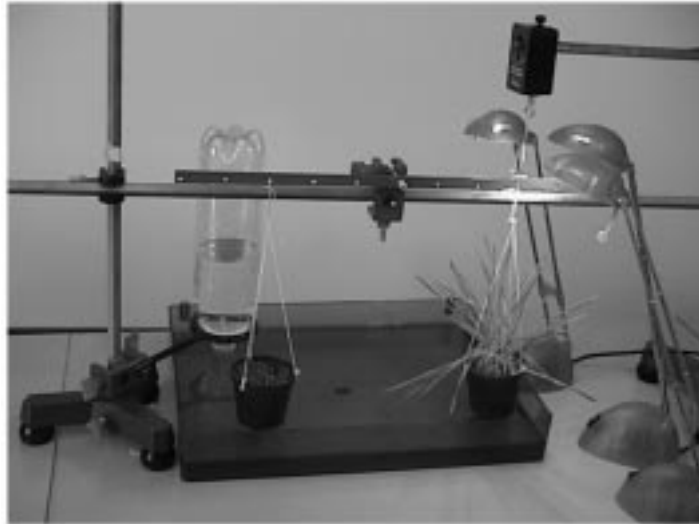


Fig. 4. Final version of apparatus for measuring dynamics of biomass growth.

pot and that of the pot containing the plant. Since the range of the force sensor employed was 20 N, the output voltage was too small to be determined directly and thus it was concluded that a voltage amplifier with an amplification gain about 100 was required. Before a usable signal was finally achieved, some further problems involving noise, filtering, etc., had to be overcome.

In the final stages of the project, a program in Delphi was developed to enable the capture of the data from the mass difference, temperature and light intensity sensors. Data was recorded every second and average values were calculated for intervals of one minute. The barley plant was illuminated with three lamps for fourteen hours during the daytime and was left in near total darkness for ten hours each night.

Although the apparatus was largely improvised, the results obtained during our first experiment turned out to be quite interesting. The curves shown in Fig. 5 are based on arbitrary units. The square-shaped curve in Fig. 5 represents the changes in light illumination (high in 'daytime', low at 'night') while the reasonably constant curve represents the temperature. The remaining curve is

the most important one, showing how the difference between the mass of the pot with the growing barley and that of the pot containing just soil varies with time.

The growth curve looks different for the first five days compared to the later behavior. While the plant is small, its mass does not significantly change as a result of the light being turned off or on. Furthermore, the mass also increases during the night as well as in the daytime. Later on, the plant appears to lose mass after the light has been turned off; in darkness the mass remains fairly stable but, after the light is turned on, the mass increases once again.

Remote sensor communication with a PC

'Wireless communication' is a term that is heard very frequently these days. Cellular phones are available to most of the students nowadays. Moreover, computer peripherals like keyboards, mouse, printer, etc., are becoming wireless and home entertainment electronic devices have a remote control. Following these trends, courses on wireless sensor systems for electrical engineering undergraduates were developed [9]. Since such courses

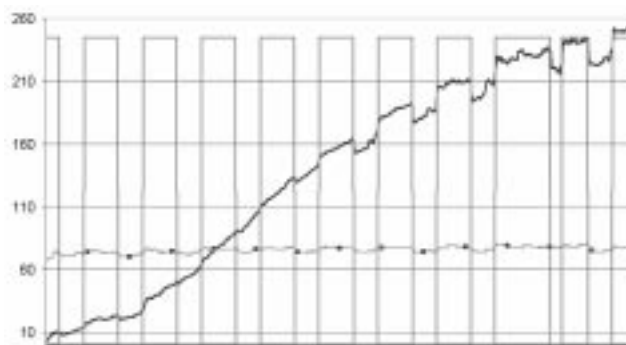


Fig. 5. Three curves representing variables during the biomass growth experiment. The square shaped pattern represents the illuminated and dark phases; the almost constant curve represents temperature; the remaining curve is a plot biomass growth (all arbitrary units).

are too complex for adoption in our teacher training programs, we examined how some of the fundamental principles of remote sensors might be introduced in electronics courses for pre-service teachers.

Wireless transmission of measured data is essential for environmental measurements. How can one study, for example, what is the temperature curve during 24-hours at the surface of the ground compared to the temperature one meter deep in the lake or how constant is the temperature in a bird's nest?

The popularity of wireless communication and a need for remote sensors for environmental measurements gave rise to the development of a project on how to design remote sensors. For data transmission we used a radio transmitter FM-TX1-433HP produced by RF Solutions Ltd [10] with 10 mW radiation power that enables good transmission within a range of approximately 200 m. Its operation is very straightforward—logical levels that are connected to the input of the emitter are regenerated at the output of the receiver. The transmitter can be explained to students as a replacement for a long wire.

Transmission of temperature information was the first example of 'wireless' remote sensing. The concept was based on temperature-to-frequency conversion using a simple RC oscillator. An adequate solution for an oscillator with standard TTL output level is based on a Schmidt trigger (IC 7414). The output signal of the oscillator is connected to the radio emitter while the radio receiver is connected to one bit of a digital input of the DAQ interface (see Fig. 6). The DAQ interface is supported by a Delphi component that can provide a high sampling rate—more than 500 kHz. No additional electronics (counters) is therefore required.

Students first determine a suitable capacitance C for the given thermistor and RC oscillator. Then they need to find a relation between temperature and frequency. The frequency of the oscillator is given by the equation:

$$f = \frac{k_1}{RC} \quad \text{or} \quad f = \frac{k}{R}$$

where k is a constant and R is resistance.

The resistance of the NTC thermistor depends on absolute temperature (in Kelvin) according to:

$$R_{NTC} = R_A e^{\beta/T}$$

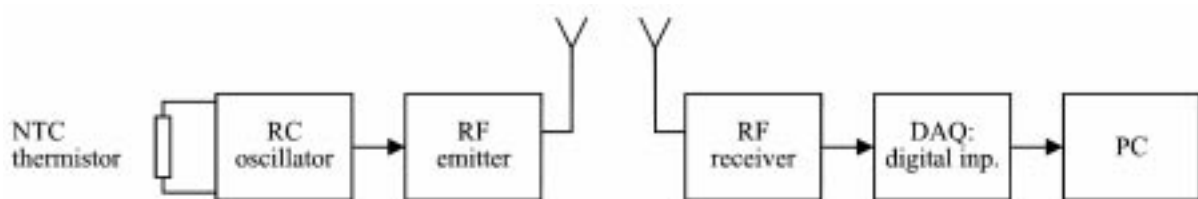


Fig. 6. Remote temperature transmission based on temperature-to-frequency conversion.

where R_A and β are constants characteristic for the thermistor. Students need to experimentally determine all three constants k , R_A and β . To conclude the project, students assemble a complete system and connect it to the PC and, finally, develop a simple Delphi program to display temperature on a computer screen. The project can be extended to various applications of similar remote temperature measurements.

The method described can be implemented only with certain variable-resistance sensors. For an arbitrary sensor with an analog output voltage (say CO_2 concentration in air), voltage-to-frequency conversion should be utilized. An alternative method is pulse width modulation, the principle of which is shown in Fig. 7. Information at the analog sensor output is contained in a duty cycle at the output of the comparator. For a 500-kHz sampling rate of the digital input, the carrier frequency was chosen to be 500 Hz—what is in most cases more than sufficient for environmental measurements.

CONCLUSIONS

Experience has shown that project-based courses on electronics can result in rich learning dividends for pre-service teachers of physics and technology. Additional advantages are obtained by introducing contemporary topics related to everyday high technology and by the use of computerized laboratory techniques as a tool, not only for simulation and data analysis, but also for data acquisition and control. It is considered important that future teachers are not only the users of up-to-date technology but are also able to understand some of its basic concepts. Since project aims are emphasized, students are motivated to apply their knowledge of electronics, computing, physics and mathematics and to get new information that is required for a particular project from the literature and the World-Wide-Web.

By selecting projects that require knowledge and skills from different engineering and science disciplines, students get experiences in teamwork [11, 12]. They realize how important is cooperation and coordination between members of the team, what is involved in time planning and management of the project, etc. With such concrete laboratory projects they develop insight into integrated curricula in a practical and applicable way.

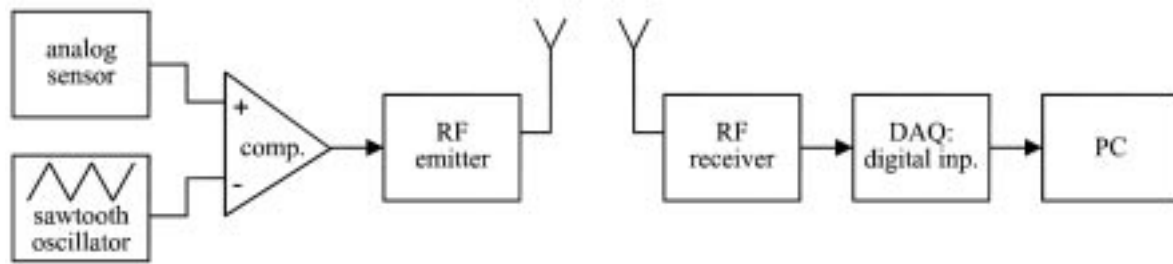


Fig. 7. Remote sensor apparatus based on pulse width modulation.

Since feedback from students after their laboratory courses was particularly positive, we were encouraged to initiate two different three-day optional courses for in-service teachers. The course for physics, chemistry and biology teachers included topics on principles of measurement, electronic sensors and data acquisition. For the in-service technology teachers, a course on robotics was developed. In the last two years, more than 50% of physics teachers were involved in the courses and about 15% of chemistry and biology teachers. At the end of the courses, the teachers completed a questionnaire surveying their experiences, troubles, advantages, influences on their approach to teaching, etc. Every teacher was required to prepare a report on at least one computerized experiment and to present the report to colleagues. The most obvious advantages reported by the trainees included higher motivation of students, more active involvement during classes, improved understanding of graphical interpretation of measured data and the possible integration of different science disciplines through experiments. The disadvantages most often mentioned included the lack of sufficient time required for preparation, lack of confidence in handling the equipment, lack of sufficient numbers of experimental sets for hands-on work, laboratories not designed optimally for such experiments.

The project is not yet at a stage where one can expect to find evidence of an increase in the number and/or quality of freshmen engineering students. Besides, because of the various societal trends that influence career decisions of

high-school students, it would be difficult to determine which such trends would affect our efforts. For all that, we desired to obtain measurable feedback, not only from trainees, but also from the students. To investigate how frequently computerized experiments are used during physics lessons in secondary education in Slovenia, a survey was carried out among approximately 200 first-year students at the Faculty of Education and the Faculty of Mathematics and Physics (both at University of Ljubljana, Slovenia). Over 61% of students sampled remembered computerized experiments from upper-secondary school and about 15% of students gave a similar positive answer for lower-secondary schools. Unfortunately, in most cases, the computer seems to have been handled primarily by a teacher alone and infrequently by pupils in a hands-on manner (3%). An important reason for this is a shortage of equipment available in high schools. We believe that this situation will improve in the next few years since the Ministry of Education has started to support schools financially for the purchase of appropriate equipment.

In follow-up surveys in future years we intend to involve more science and engineering schools. Moreover, future surveys will cover chemistry and biology as well as physics.

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