Online Experiments in Physics and Technology Teaching

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***Abstract*—Computers equipped with measurement and control interfaces have become an accepted and necessary part of science and technology school laboratories. In Slovenian secondary and undergraduate education, computer-based instrumentation and software has been developed and introduced in physics and technology teaching. In this paper, online experiments specifically developed for different school programs are reviewed. Typical examples of such experiments are briefly described and illustrated with results captured from computer screens. The present status of computer-based and classical laboratory teaching in secondary education were compared in a survey of first-year students at the University of Ljubljana, Ljubljana, Slovenia. The efficiency of the use of online experiments in schools depends on the qualifications of the teachers involved. Accordingly, courses for the training of future physics and technology teachers are outlined in which the trainee teachers are introduced to online experiments through project work. An example of one such project, involving the characteristics of optical electronic components, is presented. The contribution concludes with a discussion of specific features of the introduction of computerized experiments and some aims for their future evolution.**

***Index Terms*—Computer control, data acquisition in education, examples of online experiments, science and technology education, teaching electronics through projects.**

I. Introduction

COMPUTERS equipped with measurement and control interfaces have become essential tools in school science and technology laboratories since the first low-cost home and personal computers (PCs) appeared. From the very beginning, examples of the introduction of microcomputer-based laboratories in schools have been reported [1], [2], and similar publications have continued to appear in the literature up to the present day [3], [4]. Generally, in such applications, the computer is used to collect data, to display data numerically and graphically, and to analyze data. In some cases, it is also convenient to control the experimental conditions by driving motors, controlling heaters, and generating electrical signals. Measurement and control interfaces designed for use in school science and technology lessons, therefore, must provide both digital and analog input–output (I/O) functions [5]. Low-cost interfaces, experimental apparatus, and sensors are readily available from commercial suppliers, including specialized distributors of educational equipment and a great variety of sensors which are listed in their catalogs. In addition, many teachers and students have developed their own low-cost solutions [6], [7]. Examples of the use of computers in school science laboratories that have been described most often include motion and rotational dynamics [3], Fourier analyses [8], voltage, current and resistance measurements, and spectroscopic analysis [9]. Important aspects of the use of computers in technology education arise in interdisciplinary subjects such as robotics [10] and mechatronics [11].

Despite the obvious advantages, some teachers remain resistant to the introduction of online experiments in school lessons. Elementary instrumentation, such as mercury thermometers or moving coil meters, are preferred, although most of these teachers are happy to use a digital version of such instruments. These teachers argue that their pupils cannot understand the principles of the instrumentation and data acquisition systems used in online experiments. To overcome such resistance, it is essential to include training in computerized experiments and data acquisition systems in courses for future teachers [5], [12] and to organize workshops for teachers who graduated before personal computers became widely available.

Some knowledge of electronics is essential for the understanding of online experiments. The design of electronics courses in training programs for future physics and technology teachers, therefore, need to be more specific than that of courses for electrical engineers or applied physicists. The motivation of trainee teachers can be rather low if electronics is introduced by explaining characteristics of components or circuits, especially if laboratory work is focused more on circuit analysis than practical applications. To overcome negative reactions to standard methods of instruction, stimulating projects relevant to the chosen future profession of the students, namely teaching physics or technology, have been developed. The electronic aspect of such projects needs to be interesting and not too complicated and should involve the use of a computer equipped with a data acquisition system. Understanding of the fundamental principles of computer measurement and control is essential for future teachers of physics and technology.

II. Online Experiments in Slovenian Schools

The first examples of the use of online experiments in Slovenian physics school laboratories appeared in the mid-1980s with the ZX Spectrum and Commodore microcomputers and continued with PCs in the early 1990s. Currently, PCs are becoming a normal part of upper secondary physics lessons (pupils 15 to 19 years old) and are beginning to make their appearance in physics and technology lessons in lower secondary schools (ages 12 to 14).

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A. Hardware and Software

The provision of optimal equipment is very important for practical implementation of online experiments in schools. The I/O systems, sensors, software, and experimental apparatus adopted need to be strongly interrelated. Presumably, in most educational systems, the cost of equipment is also important. It was decided, about 11 years ago, to develop a system taking into account all requirements and limitations specific to physics education at these levels. The main objective was to design and develop a system suitable for the range of different educational levels in science and technology teaching. A computer measurement and control (CMC) interface was developed for this purpose. It incorporated fast analog-to-digital converter [(ADC) conversion time 2.5 μs] multiplexed to eight channels, two digital-to-analog converters (DACs), two eight-bit digital outputs, one eight-bit digital input, and direct current (dc) supplies ($+8$ V, -8 V, $+5$ V). Subsequently, software, sensors, amplifiers, experimental sets, power control units, and other accessories were added. Recently, sensors for online experiments in biology and chemistry offered by Vernier company (Beaverton, OR 97005) [13] have been adapted to be used with the CMC interface.

Software in Slovenian and English languages was written initially for the DOS environment and later for Windows. Currently available software comprises the following suite of programs:

1) computer-based oscilloscope (two channel) HiScope;
2) voltage–current characteristics V–I curves;
3) linear and rotational motion of bodies (kinematics);
4) a test program and libraries for programming the CMC interface.

The number of experiments that can be performed with the system is extensive, and new examples are continuously being developed. HiScope provides the greatest range of possibilities; variables such as voltage, current, force, pressure, and distance can be presented as functions of time or as a dependence of one variable on another (e.g., pressure versus volume of gas). At slower time bases, real-time presentation of variables in the form of an analog or digital meter is possible.

Hardware, sensors, and other experimental devices are available for purchase by schools. The Ministry of Education of Slovenia supported the efforts by purchasing a general license for the software. All schools in Slovenia are allowed to download this free software from the Internet.

More details about the available hardware, software, and experiments can be found on the Internet on a page entitled Computer Based School Science Lab [14].

B. Investigation Into Online Experiments in Secondary Education

To investigate how frequently online 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, University of Ljubljana, Ljubljana, Slovenia. Half of those sampled were future teachers at primary school level, and the other half were either students of physics or future physics teachers at secondary level. More than 61% of students sampled remembered online experiments from upper secondary school, and about 15% of students gave positive answers for lower secondary schools.

In the same survey, students were asked about their exposure in school to computer simulations and animations or traditional laboratory work. The results indicated that the most frequently used tool at physics lessons are traditional demonstration experiments followed by hands-on laboratory work. Comparing the ways in which computers are used in physics lessons, online experiments are employed a little more often than simulations and animations. The computer is usually handled by a teacher, infrequently by pupils (3%). Another aim of the inquiry was to investigate how the students surveyed valued each of the following pedagogical techniques: traditional demonstration experiments, hands-on laboratory work, online experiments, and computer simulations/animations. Students were asked to mark each of these approaches to teaching from “not important” (1) to “very important” (4). Only answers from those students who had reported some experience with the particular teaching approach were taken into account. Hands-on laboratory work was most appreciated (average mark 3.6) followed by traditional demonstrations (3.4), online experiments (2.9), and simulations and animations (2.8). The use of computers in physics teaching is appreciated better by students of physics (3.0) than by students training to become primary school teachers (2.6 for online experiments, 2.4 for simulations). No matter what was the attitude of students to other issues, hands-on experiments were always the most appreciated.

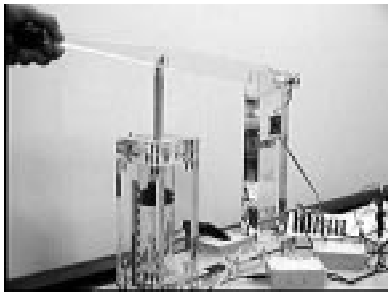
III. Teaching Electronics Through Projects

At the Faculty of Education, online experiments are mainly included in courses for future physics and technology teachers, although a study of their possible use in the context of the training of chemistry and biology teachers has recently been initiated.

In the introductory physics course, a lecturer presents *live* online experiments. In some cases, students are asked to handle and analyze the data obtained, but frequently, computer software also manipulates the captured data (plotting graphs, calculating linear regression, and fast Fourier transform). In the laboratory, during the same course, students perform both traditional and online experiments. The analysis of recorded data is highlighted, but methods of setting up the experiment are not a crucial part of students’ activities at this stage.

After completing a one-semester course in electronics and computing, students attend a further specialized one-semester course to get deeper understanding of online experiments. Future technology teachers attend a course on robotics in which they are required to assemble models of computer controlled devices (such as robot arms), build control circuits, and connect these to the CMC interface. Physics teachers take a course called *Computerized Measurement* in which they are required to set up experiments using a computer, constructing the circuits, collecting and analyzing data. In both courses, students also develop some programming skills (currently, Delphi 5).

The *Computerized Measurement* and *Robotics* courses offer practical aspects of electronics and computing to future teachers



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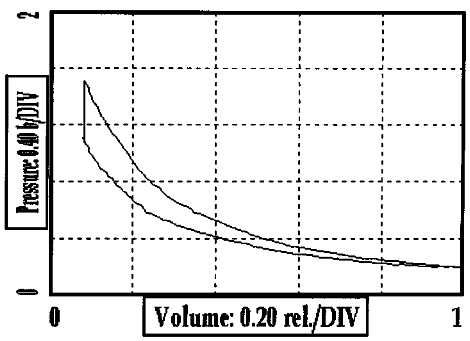
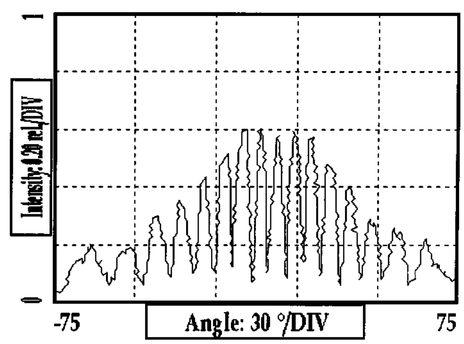


(b)

Fig. 1. (a) Apparatus for gas laws experiment and (b) the p–V cyclic change in a gas.

(a)



(b)

Fig. 2. (a) Apparatus for ultrasonic interference experiment and (b) pattern of ultrasonic waves emitted by two coherent sources.

of physics and technology. In the project-oriented aspect of their work, characteristics of electronics components are experimentally investigated and their physical background is emphasized. Examples of their technical applications are outlined.

Topics for the projects are selected from practical online experiments. Through these projects, students deal with different domains of applied electronics combining it with topics in computing and technology. Some examples of such projects are presented here.

A. Gas Laws

A pressure sensor with a range from 0.05 bar to 2.00 bar is used to measure pressure in a plastic glass cylinder with a movable piston. The cylinder has a built-in temperature sensor and electric heater. A potentiometer connected to the piston is used to determine the volume of gas confined within the cylinder. Pressure, temperature, and volume are simultaneously displayed. Relations between p, V, and T can be investigated and a p–V curve plotted. The change is almost isothermal if the piston is moved slowly and almost adiabatic for rapid changes of the piston position. Starting with an adiabatic expansion, waiting for the gas to absorb heat at constant volume, and then performing an isothermal compression, the cyclic change can be shown (see Fig. 1).

B. Ultrasonic Wave Phenomena

Two ultrasonic sources are placed at a fixed, but variable, distance apart in a horizontal plane, directed upwards and connected to 40-kHz voltage supply to provide two adjacent sources of coherent ultrasonic waves. A stick, which can be rotated at one end about an axis in the plane (the angle of rotation is measured by potentiometer—see Fig. 2), has a receiver mounted at the other end connected to an amplifier with alternating current (ac) to dc conversion. Rotating the receiver above the sources, a typical interference pattern can be obtained (see Fig. 2). One source can be removed and replaced by a vertical plate to show interference between the ultrasonic source and the waves reflected from the plate.

The intensity pattern of standing ultrasonic waves can also be demonstrated using a similar apparatus.

C. Voltage–Current Curves

Voltage versus current (V–I) curves can be plotted in real time for resistors, bulbs, diodes, and transistors. If the resistance is small, a power amplifier must be used. Students are encouraged to construct a circuit for a power amplifier themselves, whereas teachers in schools can order its commercial version.

Special attention is required when examining V–I curves at high currents. A standard way of plotting a curve is that each time the voltage is increased, the current is sampled after a time delay. The delay must be such as to ensure fixed temperature of the material at the moment of current measurement. Curves for four different specimens are compared: electric bulb, constantan wire, steel wire, and a thermistor. The thermal properties of the resistance may be deduced from the measured curves.

The temperature is not always stable. It can be shown that the V–I curve of an electric bulb becomes linear by simply decreasing the time delay to minimum. The measurement is so fast that there is not enough time for a filament to be warmed up (cold resistance). A linear V–I curve is also obtained if the temperature of the filament is kept at a chosen fixed voltage V_{ST} (stationary state). The voltage is then changed from V_{ST} to a different value, and the current is sampled immediately. After each such very short jump, the voltage is returned to V_{ST} for about a

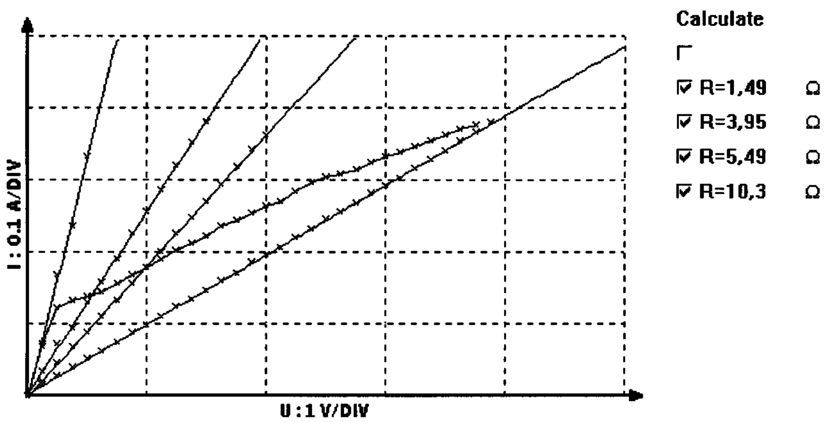


Fig. 3. V–I curves of an electric bulb with delayed measurement of I after each change of V (nonlinear), fast measurement with no time delay (largest slope), and curves at fixed V_{ST} of 0.5 V, 1.0 V, and 4.0 V (smallest slope).

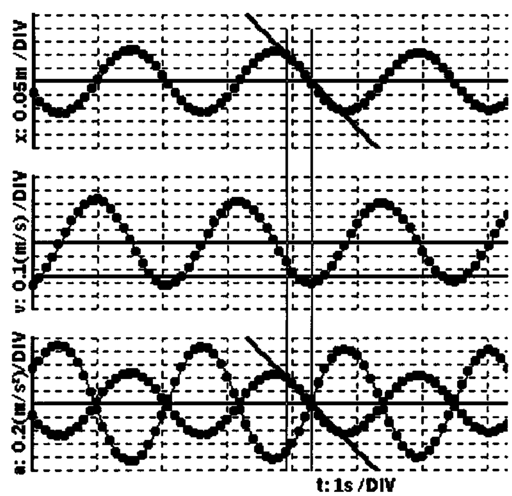
second to keep the temperature constant. In this case, changes in luminous intensity are hardly observable, and the V–I curve is almost linear (see Fig. 3). The phenomenon can be explained by analyzing the time variation of the current across the bulb at sudden voltage changes. A simplified calculation of the bulb switching time has been presented by Menon and Agrawal [15].

D. Ultrasonic Distance Sensor

An ultrasonic distance sensor connected to a computer is a convenient way to measure the position of a body in motion. A change of logical level from 0 to 1 at the digital input of the sensor triggers the emission of a short 40-kHz ultrasound pulse. The sensor detects the echo of the ultrasound, and the logical level at the sensor's digital output is changed from 0 to 1. The time between the trigging of the pulse and the detection of its echo is used to determine the distance to the moving body.

A commercial motion sensor produced by the Vernier company [13] can be interfaced to a computer via the printer port or via the CMC interface. Special software supporting this ultrasonic distance sensor was designed which besides sampling and plotting the position of a body in motion at regular time intervals, also displays the corresponding velocity and acceleration curves. The software also enables the display of curves of one variable against the other and allows for fitting selected portions of the data to linear or quadratic functions of position in time.

Technical information on how to connect the sensor to the printer port can be found on the web from where the software can be downloaded [14]. Typical curves obtained for the oscillatory motion of a ball attached to a string (pendulum oscillating in a vertical plane) are shown in Fig. 4.



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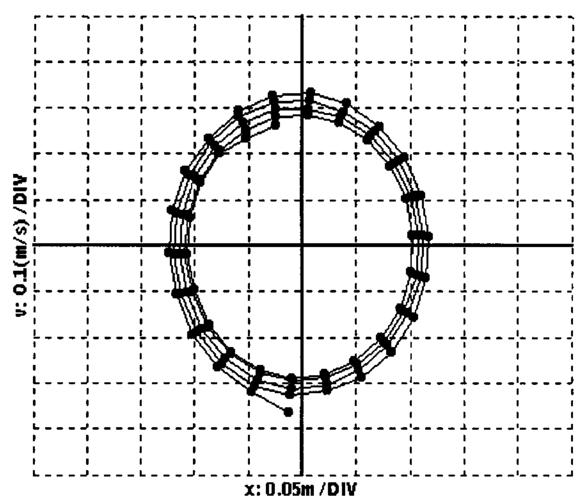

(b)

Fig. 4. (a) Time dependence of position, velocity and acceleration of a pendulum, and (b) the corresponding velocity versus position curve.

E. Transmission of Electrical Signals by Coupling a Light-Emitting Diode (LED) and a Photosensor

The project described here is a part of the *Computerized Measurement* course, previously described, for future physics teachers in the Faculty of Education. The project relates to practical applications of optical components for electronic devices. Optical properties of matter from a condensed matter physics viewpoint are only mentioned in passing because these students attend a course on modern physics later in their studies. Simulations for educational proposes concerned with condensed matter can be found elsewhere [16].

The project is presented as a study of light sources and light detectors (photosensors). In initial discussions, students are asked to tell what they already know about optical compo-

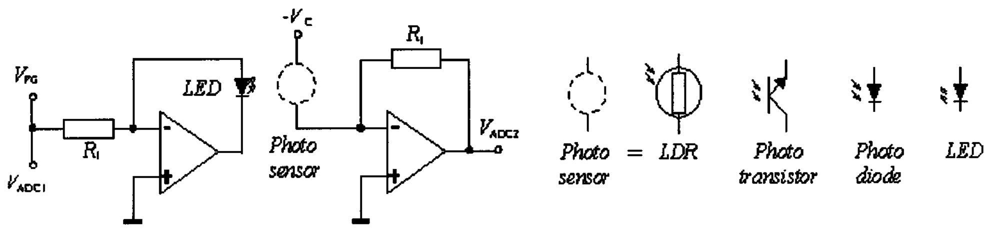

Fig. 5. Coupling an LED with different photo sensors.

nents—what they are called, what their characteristics are, and how they can be used in practical applications. Applications in which a light beam emitted by an LED is directed onto a photosensor are discussed in more detail. Reference is made to the use of a photogate as a stop clock and the general principles of optical communications.

Students are asked to design their own experiments and models using the CMC interface. Some of the suggested topics include:

1) plotting V–I curves of LEDs;
2) V–I curves of a light-dependent resistor (LDR) at constant illumination taken as a parameter;
3) transmitting electrical signals by coupling an LED and a photosensor;
4) analyzing the dynamics of a coupled LED and photosensor.

The objective of the third topic is to construct a circuit which can transform a voltage signal at the input of the circuit to light intensity and which can then be converted back to a voltage. It can be assumed that the intensity of the emitted light is proportional to current through the LED. A V to I converter seems to be a relevant choice of circuit to convert an input voltage to light intensity. For detecting light intensity, two possibilities are usually considered; one is converting resistance, and the second is converting conductance to a proportional voltage. At this point, the photoelectric effect is briefly explained as a transfer of energy from light incident on a substance to free electrons within the substance. Such clarification is necessary for a decision on whether to convert conductivity to voltage. The complete circuit with V_{FG} as the input voltage derived from a function generator and V_{ADC2} as the output voltage is shown in Fig. 5.

The ideal relationship for analog optical transmission of voltage would be linear conversion of voltage into light intensity and linear conversion of light intensity to conductance. Students are asked to derive a mathematical relationship between V_{FG} and V_{ADC2}. Finally, the proposed relationship is checked experimentally by connecting a triangular waveform as the input voltage V_{FG}. The voltage V_{FG} and the output voltage V_{ADC2} are connected, respectively, to two of the analog input channels of the CMC interface. Results are compared for all standard photo sensors, namely LDR, transistor, and photodiode. The combination of an LED with photodiode provides a relationship that is closer to linearity compared to that of an LED combined with an LDR (Fig. 6). Students use a standard spreadsheet application to numerically analyze the relationships.

An interesting phenomenon can be observed at this point. One can couple two LEDs, one as a light source and one as a photosensor (reverse biased LED). The students study various combinations of pairs of LEDs emitting different colors (infrared, red, orange, green, and blue). For example, using a green LED as the source and a red LED as a sensor works, whereas the opposite combination does not. Comparing turn-on voltages with photon energies, the appearance of photoelectrons in semiconductors is briefly explained.

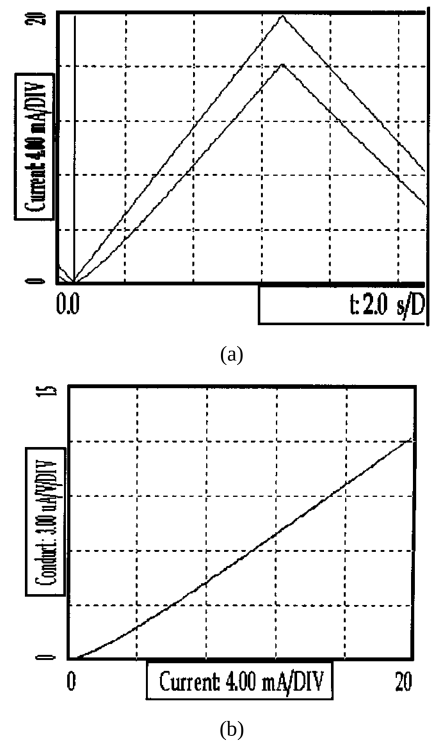

Fig. 6. (a) Time dependence of photodiode conductance and current through an LED and (b) dependence of conductance on current.

The circuit in Fig. 5 is intentionally investigated at low frequencies, and students are encouraged to study its dynamics. For the LDR, the signal at the output is clearly deformed at 70 Hz, whereas the curve for a photodiode is closer to linear even at 7 kHz (Fig. 7).

Because of the considerable importance of digital optical communications systems, replacing the triangular waveform input with square waves checks the dynamics of circuit in Fig. 5. Students are asked to compare the time response of the circuits using an LDR and using a photodiode as the photosensor (Fig. 8).

IV. Discussion and Conclusion

A computer-based science laboratory provides a range of versatile tools that enable experiments to be performed and learning

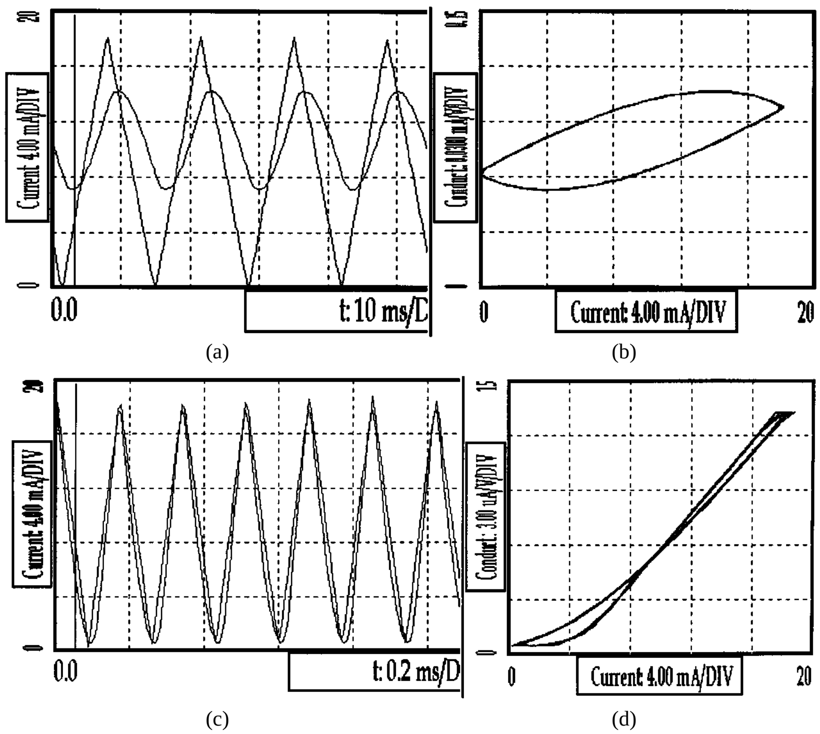

Fig. 7. Comparison of dynamic characteristics of coupled LED with LDR and LED with photodiode. (a) Time dependence of LDR conductance and current through at LED at 70Hz. (b) Dependence of LDR conductance on current at 70 Hz. (c) Time dependence of photodiode conductance and current through an LED at 7 kHz. (d) Dependence of photodiode conductance on current at 7 kHz.

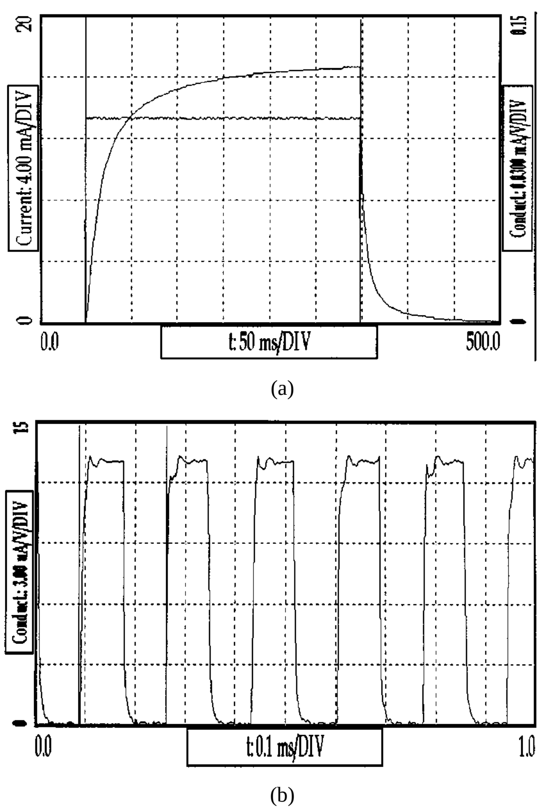

Fig. 8. Square waves transmitted through (a) coupled LED with LDR and (b) LED with photodiode. Note the different time scales.

to be achieved more efficiently than in a laboratory limited to the use of traditional instrumentation. Potential advantages include the following.

1) In a school laboratory, the quality or precision of the instrumentation is not as important as in a research laboratory. Stand-alone instruments are usually more expensive than sensors connected to a computer interface.
2) Digital storage oscilloscopes have an advantage only if high sampling rates are required [17]; thus, in most cases, these relatively expensive instruments can be replaced by a computer. Furthermore, for most applications in biology and chemistry, the time bases required are so slow that low-cost cathode ray oscilloscopes without storage are not a suitable choice.
3) Immediate feedback is available through real-time presentation of data. It was noticed by Barton [18] that pupils who plotted graphs manually emphasized the significance of individual points while, in contrast, pupils who used computers focused on general trends in the data. It was reported by Slovenian teachers that most of the pupils who had experiences of online experiments did not join individual points together with a series of straight lines, in contrast to pupils who never faced online experiments.
4) Signal processing is an important topic in courses on instrumentation [19]. Processing and interpreting the data provides a more direct relationship between the mathematical description and their graphical representation [18]. Data acquisition software should have an option to export data to text files compatible with other software. Easily available spreadsheet applications, in particular, provide significant support at the secondary science level.
5) Significant proportions of lesson time are saved by online data acquisition and display as distinct from the time needed for traditional manual data recording and graph

drawing. The time saved can be used, for example, to repeat experiments many times, varying parameters to investigate more general aspects.

6) Some experiments would be practically impossible to perform without the support of a computer.
7) Principles of computer-assisted manufacture, such as robotics and mechatronics, can be presented at secondary education level, whereas professional devices would be too complicated and expensive.
8) Using computers in science and technology teaching is a strong motivation for many students. Because computers support modern instrumental equipment and manufacturing, school laboratories should follow these trends, or they risk giving the appearance to pupils of being old-fashioned or irrelevant.

From the results of the survey and from general experiences with students, some conclusions can be drawn. Feedback from students after their practical online laboratory course was particularly positive. Pupils attending summer schools on robotics also responded very enthusiastically. Furthermore, many pupils undertook interesting projects based on computer interfacing within their noncompulsory school activities.

Significant difference in attitude to computerized school laboratories have been clearly observed between those students with and without practical experience of online experiments. Similar observations have been reported by Newton [20] and Rogers [21]. Pupils particularly liked handling equipment and performing experiments, whereas they disliked passively watching demonstration experiments. Online experiments handled only by a teacher stimulated pupils only when real-time display of data was combined with prompt questions and suggestions from the teacher. Pupils can be asked to predict what would happen when experimental parameters or conditions are changed, such as looking for trends, comparing results, or suggesting what to do next.

The most important step in the further evolution of online experimentation in Slovenian education would be to make computers and interfaces available to pupils to work with themselves. On the other hand, didactic methods have not been developed to the same level as computer-based technical equipment. It is necessary to identify which aims are best achieved with a traditional laboratory and which with a computer-based laboratory. What is the reasonable proportion of time consumed by particular laboratory methods at different levels of education? For some teaching objectives, laboratory experience is essential, whereas virtual and multimedia approaches appear to be more convenient for others. Therefore, there is a need to integrate different aspects of the use of computers in science teaching [22] with more traditional approaches to the teaching of science and technology.

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