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Computer in teaching physical experiment at a high school and university level

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Abstract

The advantages of the use of the on line physics experiments are presented on the example of Adam Mickiewicz University. The use of MBL technique in new areas is proposed. New solution for school and distant learning are presented.

1. The advantages of computer-aided measurements

It is commonly known that a computer system composed of a PC unit, an interface and measuring sensors is used as a measuring device and also for automation of measurements [1-2]. The main advantage of computer-aided measurements is the possibility of making a large number of measurements in a short time recording also the time moments of measurements. The results are obtained in the form of a table containing the measured values of a given quantity and time and are usually displayed in the form of a time dependence of the quantity measured. Using the COACH software the number of results collected in a single cycle of measurements varies from 200 to 2000 [3].

Another advantage is the possibility of measuring a few (up to four) quantities at once, e.g. current intensity and voltage. The results can be further processed by computer software.

Computer measurements ensure high accuracy of measurements (low uncertainty) which depends on the number of bites of the analog-digital conversion. It can be easily calculated that the simplest 8-bit converter differentiates 256 values of the maximum range of measurement, which gives an accuracy to 0.4%. A 12-bite converter ensures the accuracy up to 0.025%, and special 24-bite converters can ensure the accuracy to $6\ 10^{-8}$.

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The advantages following from the use of computers can be illustrated on a simple example. The simplest kinematic experiment on the air truck can be performed by the classical method and making one measurement of time at a given preset position for each pass, so in order to get 10 results 10 identical passes are needed. The results must be presented in the form of a plot, calculations must be made and conclusions drawn, which can take at school even two hours. With the use of COACH software, interface and position sensor we are able to perform 200 readings per a single pass and the corresponding time dependencies of position and velocity are shown on a monitor screen. The results are obtained in the time of one pass, so in seconds.

Other advantages of the use of COACH are connected with a great variety of ways of results processing offered to the user's choice. 2000 of measurements gathered in a time period determined by the experimentator are stored in the computer memory. The software enables to process the data in a way chosen by the experimenter, i.e.: in a single calc-sheet, in chosen coordinates; to read out the coordinates of a chosen point, to select part of the results for further processing, to calculate the area closed by an experimental curve (integration and differentiation), approximate the experimental results by a chosen mathematical curve, model physical processes etc.

2. Computers aided experiments in university laboratories

On different levels, different technical solutions can be applied. On the level of physical laboratory for beginners the best choice so far is the COACH system because of its universality, low price and simplicity of control [4]. But also other equivalent systems are used in order to cover all branches of physics. At our university (Adam Mickiewicz University, Poznań, Poland) the Physical Microcomputer Based Laboratory (MBL) has been working since 1993, it has 32 measurement stands shown in Table 1 and about 15 stands are based on the COACH package [4-6]. The package has relatively modest hardware requirements, so that the computer lab can use computers withdrawn from research use and the measurement stands can be assembled of the school equipment or classical laboratory equipment. Of course, the special hardware and software offered e.g. by Leybold, can be used, but it is usually much more expensive and used for one experiment only.

Table 1. The list of MBL experiments

1. Experiments on air-track
2. Conservation of momentum
3. g-value measurements
4. Computer aided Atwood machine
5. Mathematical pendulum
6. Examination of the dumped oscillations
7. Oscillation of the composed pendulum

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8. Mechanical resonance
9. Torsional oscillations
10. The velocity of sound
11. The harmonic analysis of the beats
12. The acoustic resonance in a tube
13. Thermal conductivity, by gradient and temperature waves
14. The Boyle-Mariotte experiment
15. The faze transition ice-water
16. Specific heat of the liquids and solids
17. Electric resistance versus temperature measurements
18. Discharge curve of the capacitor
19. Characteristics of diodes and transistors
20. Characteristics of photoelectric elements
21. Examination of the Faraday induction law
22. Effect connected with switching off or on a coil
23. Resistance of the condenser or coil in ac-circuit
24. Phase shift in ac circuit
25. Resonance in electric circuits
26. Resonance between electric circuits
27. Hysteresis of magnetic materials
28. Diffraction of light on slits
29. Franck-Hertz experiment
30. The ionising potential of hydrogen atoms
31. The absorption of ionic radiation
32. Velocity of light

In preparation:

1. Examination of the thermal expansion of water
2. Measurement of the Figenbaum constant
3. Quantum effects in a dc circuit
4. Distribution of energy in thermal radiation
5. The use of the CCD camera in cinematic experiments
6. Examination of the Doppler effect
7. Construction of the remote experiments

3. New areas of experimentation

The use of computers permits to extend the areas of experiments into the fields not covered by classical equipment. A few examples of such new experiments are given below:

The magnetic hysteresis loop [2] is measured in simple ac. Circuit in the very short time of 1 cycle. The results are very exact and the method is useful for all kinds of feri magnetic materials.

Light intensity distribution in a diffraction or interference pattern. The measuring setup and exemplary results are shown in handbook [2]. The light detector movement is controlled and a special software written by Prof. R.Lincke [7, 2].

Measurement of light speed in an optical waveguide [2]. The idea of the measurement is to measure the time of a light pulse passage through the optical waveguide. The experiment requires more advanced hardware. The experiment

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uses a generator of rectangular light pulses a telecommunication equipment for driving light pulses into the waveguide and a fast computer able to record a time difference of microsecond.

Chaos in an electronic circuit [8-9]. The principle of measurement is shown in Fig. 1. Chaos is produced in an electric resonance circuit in which the capacitor has been replaced by a nonlinear varicap diode.

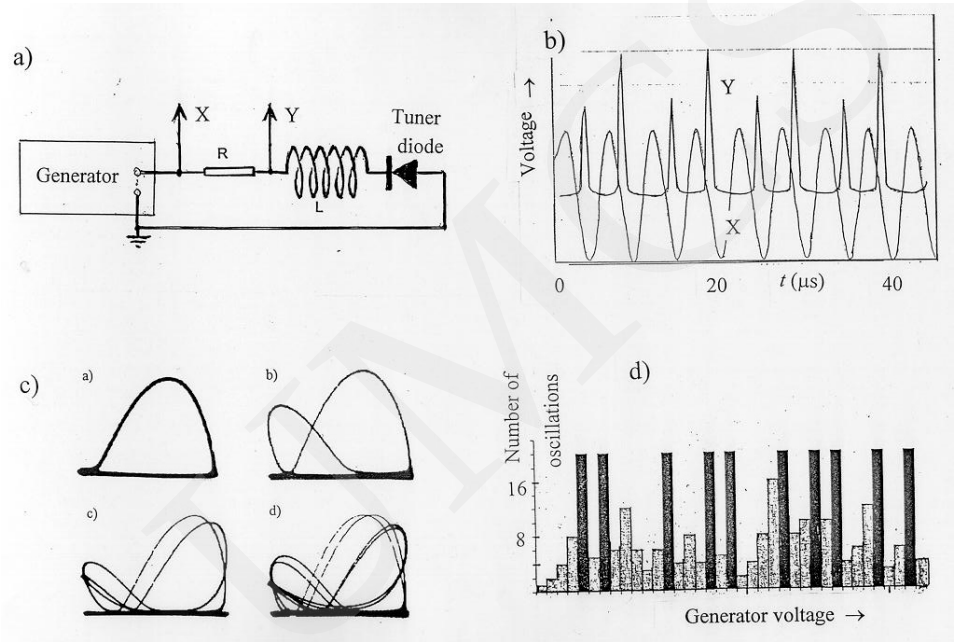

Fig. 1. Chaos i *a.c.* circuit: a) The circuit with the tuner diode, b) The output signal after first bifurcation, c)The cascade of bifurcations on the oscilloscope screen, d) A number of oscillation *vs* voltage of generator

The chaos is generated through bifurcations or doubling of the period of the vibrations with increasing control parameter being the voltage U_i supplied to the circuit. The frequencies used in these experiments are of the order of 100 kHz and therefore more advanced high frequency interface is necessary. We used the "Digital Storegescope HC 3850". On the basis of the results of measurements, a value of the Feigenbaum constant

$$d = \frac{U_i - U_{i-1}}{U_{i+1} - U_i}, \tag{1}$$

was determined as $d_{exp} = 4{,}67$, with the standard deviation of $u(d) = 0.25$ against the theoretical value 4.669. The experiments introduce the notion of a deterministic chaos and the results are reproducible.

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The quantum effects in a constant current circuit [10-11]. The idea is very simple, switching on or off of the low intensity current (of the order of pA) is accompanied by rushthe current related to the particle structure of electric charge (results of measurements are presented in Fig. 1). The equipment demands are high: a high class computer and a nano-contact of a controlled electrode distance. The contact can be realised between two pieces of very thin wire made of a noble metal (preferably gold). The wires can be placed one over another and the experimenter can observe the effects of random vibrations. Many attempts are needed to get the effect shown in Fig. 2. In future we plan to make a contact controlled roughly by a micrometer and more exactly by a piezoelectric effect. The experiment is difficult but it has profound didactic importance as it permits observation of quantum effects.

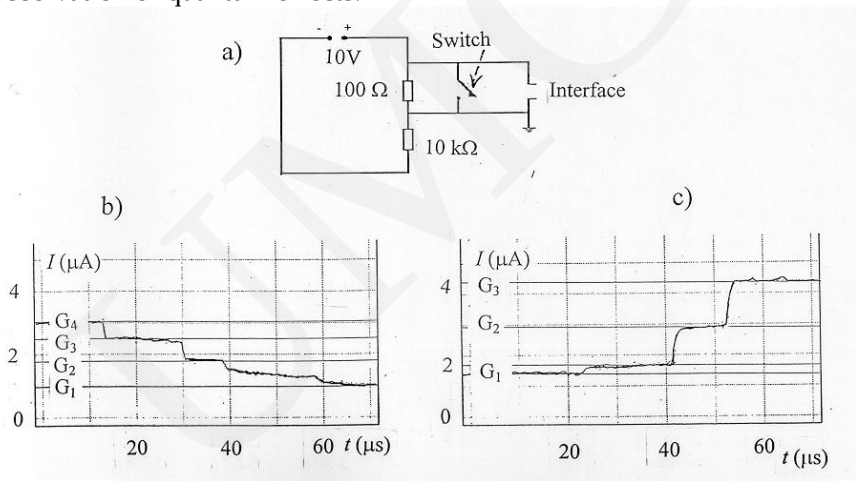

Fig. 2. Quantum effects in *d.c.* circuit: a) the circuit, b) switch off effects, c) switch on effects. Resultants obtained by the use of computer set with the interface HC 3850.

4. Computer mini-laboratories at schools[1]

Implementation of computer-aided experiments at schools is still a problem. The most important restrictions are too little time devoted to sciences, lack of funds for the purchase of hardware and software and the need to prepare and interest teachers. The time limitations can be overcome if the computer-aided experiments are introduced within the subject of computer science or computer programming. Such an introduction is justified because as it shows the applications of computer and at the same time provides new contents in the fields of physics, chemistry, biology or mathematics. Computer laboratories will sooner or later be organised in the majority of secondary schools, what we

[1] A. Maziewski, Białystok University, projects for Polish Ministry of Education, G. Karwasz, Słupsk Univerity, project Leonardo da Vinci.

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recommend is the use of the COACH software (the best in Europe) and preparation of teachers. A pilot implementation can be made in a few chosen schools, which needs the following conditions.

1. The universities preparing future teachers should start laboratories with the computer-aided experiments and network experts in the use of computers for teaching natural sciences.
2. The same universities should prepare teachers from a given school to use computers for computer-aided experiments.
3. The schools whose teachers have been trained should be supplied by the Ministry of Education in the hardware and software needed.

At present computer laboratories have been organised at a few universities so the background has been prepared.

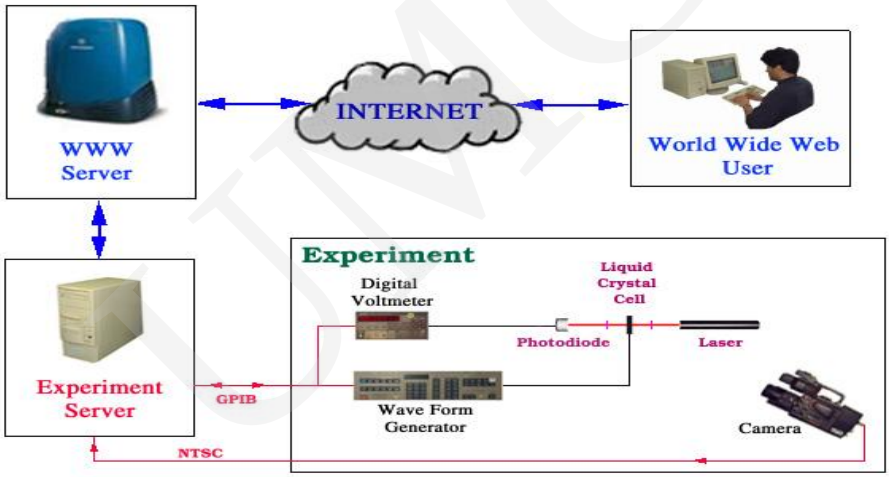

Fig. 3. The idea of the internet experiment [12]

5. Physical internet laboratories

The idea of internet laboratory also known as the distant-laboratory or remote laboratory is shown in figure 4 [12]. The measuring stand in such a lab must be fully automated and computer controlled. E.g. in the experiment on induction, a computer signal controls the introduction of a magnet into the coil and simultaneously the computer measures the time course of the generated voltage signal. The results are obtained in the same form as when the experiment is performed directly. The measuring stand is equipped with a CCD camera supplying the picture to the computer. Of course the experimenter can be at an arbitrary far distance (even in another continent) and internet is the only link between the experiment stand and the observer. Such a computer stand does not permit any changes in the measuring stand but it permits performance of an experiment at the measuring stand and collecting and processing of the results at

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a different location. The software should be adjustable to a few versions of the experiment. Different experiments can be performed at different laboratories (universities) linked into a network covering the educational programme in natural sciences. A student at one location would be able to perform all experiments in a given field. The internet laboratories could also be good solutions for underequipped schools. They can be organised as an international network and the first attempts at their organisation have been made.

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