Virtual instruments perform real experiments in the physics class

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The absence of appropriate experimental demonstration tools often hinder the demonstration of the curriculum of the secondary and higher education in Hungary. Instead of continuous efforts in the restoration of the amortised facilities, new measurement stages based on digital signal processing and virtual instrumentation give an alternative. When real physical, chemical, etc. phenomena are mediated by today`s multimedia technologies, the experiments` scientific background may also have an easier access to students familiar to the computer world.
In our presentation we show selected classroom experiments using self-developed data acquisition units [1] and virtual instrumentation to demonstrate mechanical oscillations, acceleration, the propagation of thermal waves and some basic optical and acoustic phenomena. We emphasize the possibilities in the education of sensor technology, and report on the transfer of the virtual instrumentation of the students' labs to real research, industrial and medical diagnostic applications.

INTRODUCTION

In the preceding PTEE conference (2000, Budapest) we presented an intelligent data acquisition unit DAS1414 [**1**, **2**] which has a gradually increasing influence in the scientific and technological research, and variants have already been installed in industrial plants. Also at that conference, we reported on the introduction of virtual instrumentation technology into the education of physicists and communication engineers in a two-semester course and a student laboratory [**3**] equipped with personal computers and DAS1414 devices. In the meanwhile, the curriculum obtained accreditation, i.e. in the education of communication engineers and informatics engineers. Also, the DAS1414 unit gained numerous new applications ranging from control of a pulsed laser deposition vacuum system and other laboratory setups to process control in an earth gas refinery plant [**2**, **4**, **5**].

In this contribution we report on our new achievements in the secondary school level with the application of digital and virtual instrumentation [**6**]. The secondary school is the last stage of the education where one can obtain basic knowledge of very different arts and sciences in a conceptual, integrated form. The secondary school is, moreover, the last chance to make at least an impression of physics and chemistry on pupils who will later study arts or social sciences, and also on those who tend to choose between physics, chemistry, biology or engineering. Experiment-oriented or experiment-assisted teaching of physics, exhibiting basic and even more complicated natural phenomena, not only helps to form a positive attitude of pupils to science, but also gives a good experience to those who turn aside from pure descriptions and equations. We developed a series of spectacular experiments on the base of digital technology and virtual instrumentation to help experiments to re-enter the classroom. The basic concept and a low-cost multichannel data acquisition unit will be described. We also present a couple of simple but spectacular experiments.

THE CONCEPTS AND THE SOLUTION

Setting up demostrational experiments needs much time and effort. Setups have to be thoroughly tested and resetted before they are displayed. The collection and fitting of the pieces is sometimes difficult and may require technicians work as well. Clearly, safely operating systems with well fitted components can be purchased as commercial kits, but such systems are not only rather expensive, but they do not perfectly fit to the profile of the school and curricula and also the teahers' creativity is not efficiently exploited.

Some concepts should be considered in setting up new experiments, or during the refurbishment of a whole demonstration lab or classroom. First, the demonstration tools should be known very well. This is not necessary related to all details of operation, but we must know precisely, which is the expected response of an instrument in given circumstances, and what are exactly the limits of operation. Further, the instruments should not be objected to aging; otherwise much work is spent to checking, calibration and refurbishent. Some level of standardization is necessary which allows the users to discuss and share their new experiments, developments and achievements upon consultations and conferences. The tools should be able to visualize processes which take place on too short or too long timescale to be obvious, and to make the events and key information visible to everyone in the classroom.

Our solution is the application of **virtual instrumentation** in the teachers' demonstration experiments. The virtual instruments are *softwares* which, concerning their functions and appearance, imitate real or realistic instruments. Although being "realized" by a software, the measurements performed by virtual instruments are definitely real. These devices are bound to the real environment via sensors and converters, and can influence it via actuators. The displayed quantities can be in a closer relation to the parameter to be measured than in the case of "real instruments", as far as the real parameters are measured through abstracted general physical quantities and the parameter itself is known after certain numerical calculation — vitrual instruments can easily involve this interpretation as well. The larger proportion of the whole instrument is represented by software, the more versatile, flexible and improvable instrument do we have.

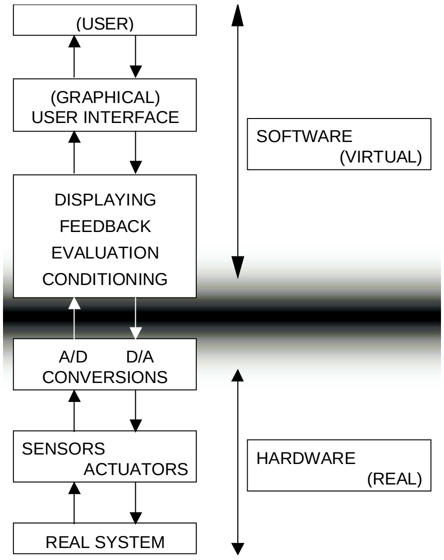

FIGURE 1. The virtual instruments. The signals of the real system will be converted into electronically measurable signals (voltage or current) by sensors. Analog-to-digital (A/D) conversion changes these signals into numbers, which will be further processed by the software. The occasional response will also be expressed in numbers. The digital-to-analog (D/A) converters change these numbers into — typically — electric signals which drive the actuators to influence the real system. The shaded zone represents the boundary between the hardware (real part) and the software (virtual part) of the instrument.

In our view, a basic laboratory for classroom measurements can equipped with four components:

1. The physical, chemical, biological, etc. hardware/basis/background of the experiments. This represents the real system to be investigated.
2. A set of different sensors (and actuators) for various physical quantities.
3. A fast high-resolution multichannel sensor interface with standardized sensor ports and binary I/O channels. This device converts the quantity, measured by the sensor, into numbers directed to and processed by the virtual instrument.
4. A set of virtual instruments representing the specific experiments to be performed. They are assemblies of a front panel and the mathematical and communication mechanisms making/organizing the instrument to function.

The quantities that can be measured

The analog-to-digital converters allow electric signals to be measured (digitized) (almost) directly. Other quantities must be turned into voltages by sensors and signal conditioning (and transducers). Below we give a very short sampled list of cheap and easily accessible sensors that can be used in classroom experimentation, in line with some typical applications.

Potentiometers — The resistance of these variable resistors depend on the position of the third electrode. Linear sliders measure the position of object along a linear section, while rotary potentiometers are sensitive to the rotational position of their axes. With one time dependent measurement one can calculate both velocity and acceleration for a linear motion, and the corresponding values for rotation.

Thermistors, termocouples — Measurement of the temperature of objects. Time and position dependent measurements can demonstrate the propagation of heat in materials, phase transitions, etc. Educational calorimeters or tempearture controllers can also built easily.

Photodiodes, photoresistors — Light intensity can be measured directly, absorptivity and reflectivity measurements can also be arranged. These sensors are very common in the everyday life.

Acceleration sensors — Acceleration, gravity and angle of inclination can be determined using this class of sensors. The acceleration, even though it is one of the most important quantity of dynamics, could not be visualized by the classical measurements, the only correct treatment of it is the calculus! In the practice, such sensors are used in mechanical resonance analysis, for alarm systems, fire works, and in the seizmology — some of these applications can also be easily modelled in the classroom.

Force sensors — Used in dynamics (collisions, friction, etc.) or in statics (equilibriumof several forces, measurement of weight).

Pressure sensors — For pressure of gases and liquids; hydrostatics (including hydraulics), hydrodynamics (Bernoulli law, flow resistance). With mechanical transducers, we can easily measure blood pressure or the phases of resipration.

Hall sensors — Their basic function is the detection of magnetic field (e.g. close to an excited wire or coil), but they can also be used for position or proximity sensing, revolution speed and velocity measurement.

Microphones — The sound pressure sensors can be used to measure sound velocity, to demonstrate the Doppler effect, echo, acoustic resonances. In the combination with (mathematical) spectral analysis the components of human or musical sound can be determined.

Strain gauges — Besides elastic distortions of bodies, very small forces and axial rotations can be measured.

Many other sensor families could also be enumerated (chemical sensors, etc.), but we must not forget to mention the actuators, i.e. the devices which are designed to affect the parameters of the environment. For an example, the „inverse" of the position sensors are the motors (stepper or continuously moving types); the temperature of an object can be influenced by resistive heaters or Peltier coolers (semiconductor based heating or cooling devices). The actuator of illumination is a lamp, that of force is electromagnet.

The multichannel sensor interface

For the support of the virtual instrumentation, we have developed the DAS12 microcontroller based data acquisition unit. The DAS12 was designed with somewhat lower specification (see Appendix) than our previous DAS1414 to make it (financially) available for secondary schools and student laboratories of universities.

The data acquisition unit has the task to accept and digitize sensor signals with high sampling rate (100 kS/s at maximum) and strict timing. The unit can record the time course of one or more measurable parameters, also with simultaneous generation of DC voltage signals. The ease of operation is aided by the standardized sensor ports, designed to connect passive and active sensor electronics as well, moreover, smart sensors with direct digital response.

The unit communicates with the host computer via the RS232 interface at 57.6 kBaud, which ensures fast transfer of the measured waveforms, and up to 3000 data/s continuous upload rate of 12-bit data to the PC. The occasional amplification, buffering, timing, signal generation etc. are fully coordinated by the DAS12 unit. This helps the users to focus on the real measurement task, using a specific control language of DAS12, which is interpreted by the built-in microcontroller.

The virtual instrument

As already mentioned, the major part of a *virtual instrument* is „realized" by software, which *can be modified quickly* and easily — this is its main advantage. However, this is valid only if an appropriate developing environment is available for the definition of the user surface and the internal algorithm of the instrument. As one of the most widespread and most efficient virtual instrumentation environment, we used LabVIEW [**7**] to develop our experiments. In LabVIEW, the front panel of the instrument may contain simple numerical controls (inputs) and indicators (outputs), buttons, switches, and also analog-like gauges, „thermometers", sliders, charts and even three dimensional graphs, etc. After the front panel, the „circuit board" has to be drawn, which means the graphical definition of the algorithmic background of the functions. This only needs a couple of mouseclicks. The icons representing the operation to be performed on the data originated from the front panel or communication channels are deposited in the „diagram" area and the data flow is defined by „wires" from the result of one operation to the input of another one. The ease and versatility of the G programming „language" of LabVIEW enables to focus constantly on the experimental task.

Since the virtual experimental instruments can be developed directly by the students, the instruments are no longer „black boxes", as the internal structure is known in all details. While pupils can also develop their own devices accoding to personal ideas and creativity, they must trust only a few points concerning signal conditioning and analog-to-digital conversion.

SELECTED DEMONSTRATION EXPERIMENTS

The motion of a pendulum

The swing of a pendulum (Fig. 2) can be followed by a fine rotary potentiometer: rotation results in changing voltage at the sliding contact. Using DAS12, the number of 12-bit resolution data allows the precise calculation of the first and second time derivatives of the angular position, even at small amplitudes. The harmonic and anharmonic cases can ve well visualized.

Acceleration of a body on a spring

The accelerometer mounted on an oscillating object (Fig. 3) can give direct information on the acceleration. For vertical motion one can observe sinusoid time course of the acceleration, while with e.g. horizontal initial velocity there is a coupling between linear oscillation and swing, resulting in modulation in the acceleration oscillations.

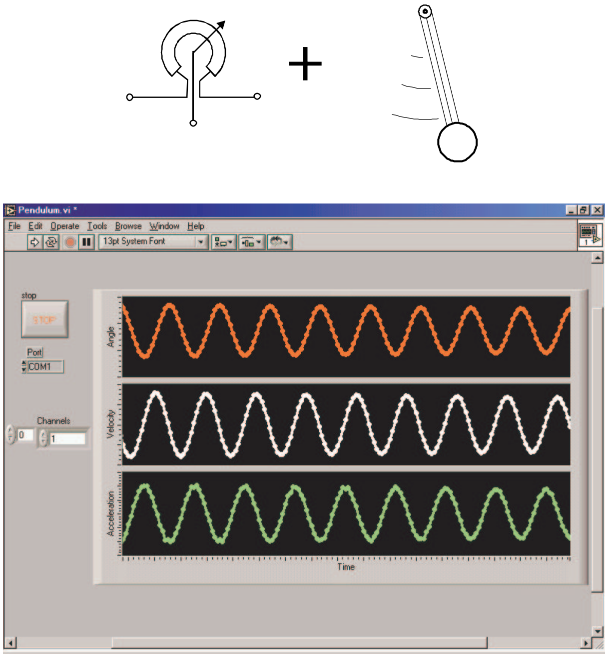

FIGURE 2. Combination of a pendulum with co-axial rotary potentiometer. The curves on the front panel of the virtual instrument show the angular position, velocity and acceleration (from top to bottom, respectively).

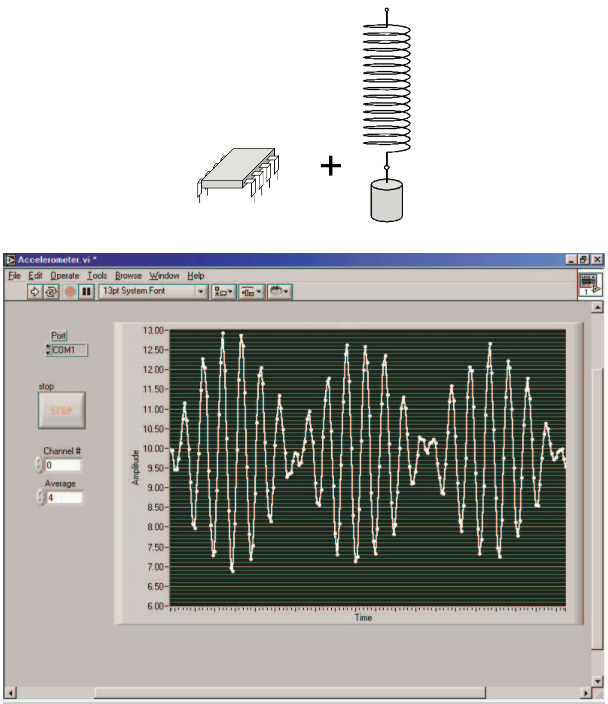

FIGURE 3. Combination of az acceleration sensor chip and a body hang on a spring.

Damped oscillator

The damped oscillations of an RLC circuit (Fig. 4) can be explored by the measurement of voltage as a function of time. Depending on the values of the components, one can observe different decay times, even the aperiodic case.

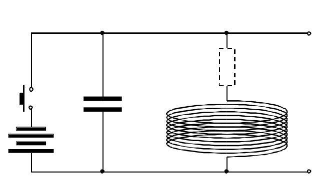

FIGURE 4. The sketch of the RLC circuit used in the demonstration.

Human respiration (Pneumobelt)

A simple rubber tube fixed around the human breast (Fig. 5) can serve as size-to-pressure transducer. The different phases of breathing can be distinguished in the pressure vs. time diagram. It is edifying to measure the rythm of the spontaneous breathing in rest, during physical activity, speaking of singing.

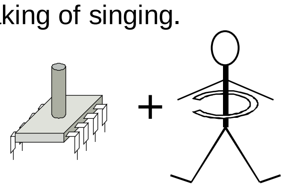

FIGURE 5. The Pneumobelt consists of an elastic tube around the waist and a pressure sensor.

Acoustic modes of a tube

An open or terminated tube possesses resonance at specific frequencies. The excitation and test can be realized using a speaker and a microphone (Fig. 6). Different excitation methods can be applied, like sinusoidal waves with stepwise changing frequency, chirp, or even white noise. Concerning the evaluation, the frequency dependence, the time dependence or the power spectrum, respectively, are characteristic to the acoustical modes. It is quite impressive to simply blow the end while all excitable modes can be distinguished in the power spectrum of the measured signal.

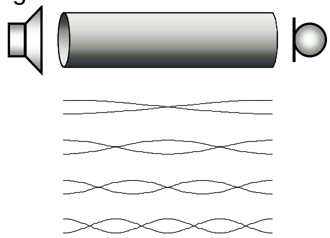

FIGURE 6. The sketch of the experiments for the measurement of the acoustic modi of a tube.

Acceleration upon free fall

Let us drop and then catch a broomstick, fitted with an accelerometer, in vertical position (Fig. 7). Before and after drop, the accelerometer measures zero, but during free fall it experiences an acceleration equal to g. The the end of the fall a large value (vertically upward) can be measured due to quick deceleration. If we let the rod slip down slowly, intermediate acceleration values can be measured, moreover, it will be surprising how difficult control mecahnisms are built in into our hands.

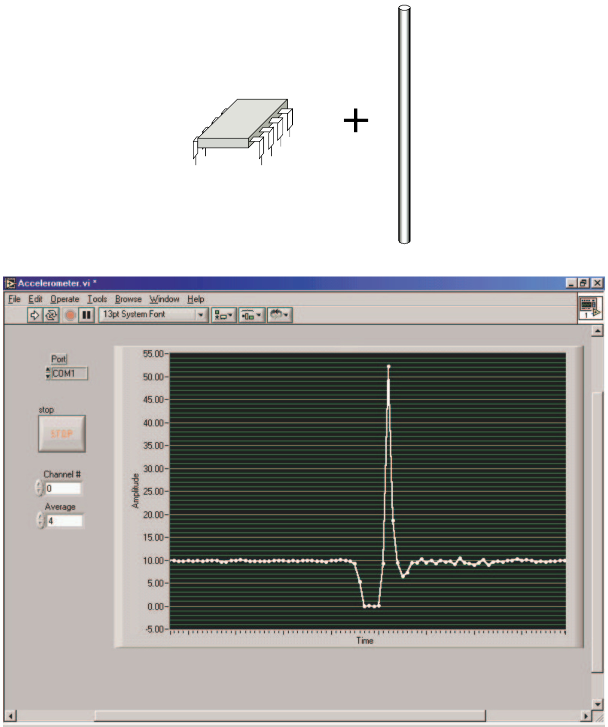

FIGURE 7. Combination of az acceleration sensor chip and a long bar. The virtual instrument has measured the acceleration during free fall and the quick deceleration thereafter.

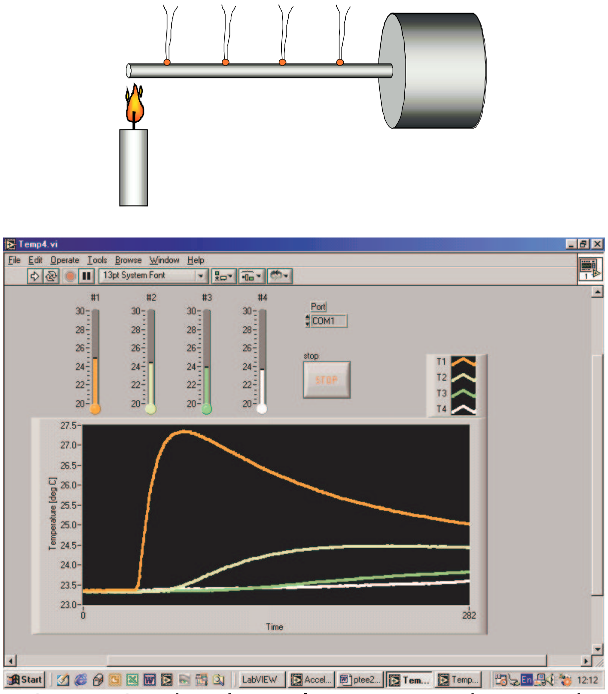

FIGURE 8. The thermal wave experiment. The four curves correspond to the temperatures at the four equidistant points.

The propagation of thermal waves

Due to short but intensive heating of a free end of a metal rod, a thermal wave propagates through the whole length. The local increase of the temperature can be measured by small thermistors fixed in small holes in the material (Fig. 8). In our setup, the other end of the rod is turned into a larger metal piece (a buffer). The overlapping local temperature versus time curves make clearly understandable the propagation of thermal waves, the thermal equilibration, the effect of the buffer and the meaning of the thermal diffusion length. Different metals and geometries can be compared and the effect of thermal isolation can be emphasized.

REASONS FOR VIRTUAL INSTRUMENTATION

Virtual instuments are very efficient experimentation tools — but we must not perform every demonstration in this framework. Many experiments are of historical importance, and we must mediate the elegance, purity, or sometimes, the troubles of the original experiments of Galilei, Newton or Kirchhoff. The classical experimentation tools must exist there in the classroom. However, we are not afraid to replace the traditional demonstration tools with the new digital measurement technology. There are several reasons for it.

1. The traditional demonstration tools aged, broke down or disappeared. Now, many tools can be replaced by one single hardware and the respective virtual instrument, thus this is a cost-efficient way.
2. Due to the rapid development of science and technology, more and more knowledge is considered as basic and general. On one hand, and increasing level of abstraction (and an increasing level of computerization) can be acceptable, and on the other hand, it becomes impossible to start and build the disciplines from the same basics as before.
3. The students may find the computer assisted demonstrations more attractive.
4. The students may find it attractive to face with things of their everyday life — in another aspect.
5. The visibility of our experiments becomes better, reliability will be improved. An easier overview can be obtained, there are less „black boxes", because the operation of the instrument is well known.
6. Experiments can be „downloaded" through the Internet, if necessary. When being in a good shape, the teacher's possibilities in the experimentation are unlimited.
7. It is easy to cross the boundaries between disciplines. There are sensors specific to chemical an biological systems, it is possible to measure graphics, music, etc.

SUMMARY

We demonstrated the applicability of virtual instrumentation technology in classroom experiments. Experiments, showing both the essence and the complex nature of phenomena can be performed efficiently, reproducibly and reliably. The method assists well the interdisciplinar way of thinking.

ACKNOWLEDGEMENT

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[**7**] http://ni.com

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APPENDIX

DAS12 intelligent data acquisition unit

8-bit 8052 compatible microcontroller
32 kByte internal memory
optically isolated serial interface (RS232) at 115200 Baud
4 differential analog inputs, 12 bit resolution
2 independent analog outputs, 12 bit resolution
100 kHz sampling frequency
4 general purpose sensor ports
amplification of the input signal tunable between 1x and 1000x
fitted and calibrated sensors

LabVIEW driver software

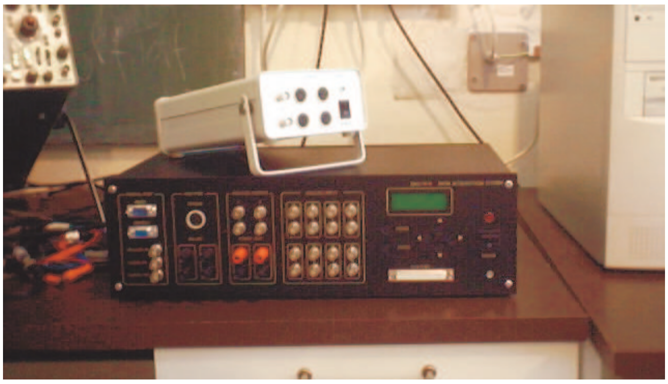

FIGURE 9. The DAS12 (top) and DAS1414 (bottom) devices (http://www.noise.physx.u-szeged.hu).

DAS1414 intelligent data acquisition unit

16-bit fixed point DSP
80 kByte internal memory
1 Mbyte SRAM internal memory (optional)
internal IDE harddisk (optional)
16-bit 1MHz ΣΔ A/D onverter (optional)
optically isolated serial interface (RS232) at 57600 Baud
8 differential analog inputs
    two simultaneously sampled banks
    14 bit resolution
    programmable amplification of the input signal (1x, 10x, 100x)
    -30V..30V overdrive protection
4 differential analog inputs
    14 bit resolution
    2 power outputs
300 kHz sampling frequency
Synchronous sampling measurements and waveform generation
4 general purpose sensor ports (24 bit resolution)
2 SPDT ralais
2x8 bit TTL I/O

LabVIEW driver software

Programmable internal and external trigger, clock source; pretrigger function