Remigiusz J. Rak and Andrzej Michalski

Education in Instrumentation and Measurement: The Information and Communication Technology Trends

This column gives a review of reasons for developing and adopting a new Web-based model of teaching in the field of instrumentation and measurement. There is included

- a description of the Internet and a multimedia-based educational model
- a description of the structure and tools of the electronic books and virtual laboratory
- a description of the distance learning provided by Warsaw University of Technology (WUT), Warsaw, Poland.

Most of the recent trends in the area of instrumentation and measurement come from different branches of science and technology. For computer science, we understand a science dealing with design, realization, verification, implementation, and servicing of information processing systems, taking into account software, hardware, organizational, and human aspects. Computer engineering means the wide implementations of computer science. Information technology (IT) is the set of elements (computers, peripherals, networks) and tools as well as other technologies (including communication) that provide versatile utilization of information. The term "information and communication technology" (ICT) joins together information, computers, computer science, computer engineering, and communication. ICT is growing very rapidly, creating great new possibilities and giving us new tools, that we have to learn and creatively implement. At the same time, ICT creates new tasks and challenges.

- expansion of a new technology very often exceeds expectations, ideas, and imagination
- people tend to observe the growth of science and technological progress with fear and see it as a threat
- a high level of unemployment, competition, and environment devastation can feed the fear
- some people are forced to change their jobs many times in their life
- there are many people who cannot continue working at a high-activity job all their life, and they fall behind
- globalization produces many structural changes, but not all people can take part in them.

Education is an answer for these challenges.

- Education prepares people for work and life. It helps people to understand what is going on in the world, refresh their knowledge, and follow the changes.
- Educated staff, capital, and technology are all necessary. High tech comes easier to the regions with educated staff.
- In an information society, the highest priority levels should be generality, universality, and necessity of education.

What is the best way to implement the new ICT tools in research and development and education? The best way is distance learning.

Many societies have provided and developed new systems of distance learning based on the assumption that education should not be separated from our professional and family life. The advantage of distance learning over a traditional model of education is its flexibility. The model of education and its tools are directed to the needs of an individual; it enables self-managed learning, saves time, and ensures cost savings, including travel and accommodation costs. The education is usually home based, which guarantees comfortable learning conditions.

The traditional model of education is based on direct face-to-face contact between student and teacher, in which textbooks play a role of supplementary self-learning tools. New developments in the area of ICT have enriched a traditional classroom with new tools, improved learning quality in both residential universities and geographically dispersed learning groups. In the behaviorism model of learning, a computer and the Internet were considered a blackboard with higher functionality. In the constructive model, a computer and the Internet were the cognitive tools.

Of all the technical innovations, the Internet has become an indispensable tool in introduction of technology to education, and its growing impact on the future of the educational model is inevitable.

A computer and access to the Internet enable

- e-mail correspondence
- access to didactic materials stored on Web sites and CD-ROMs

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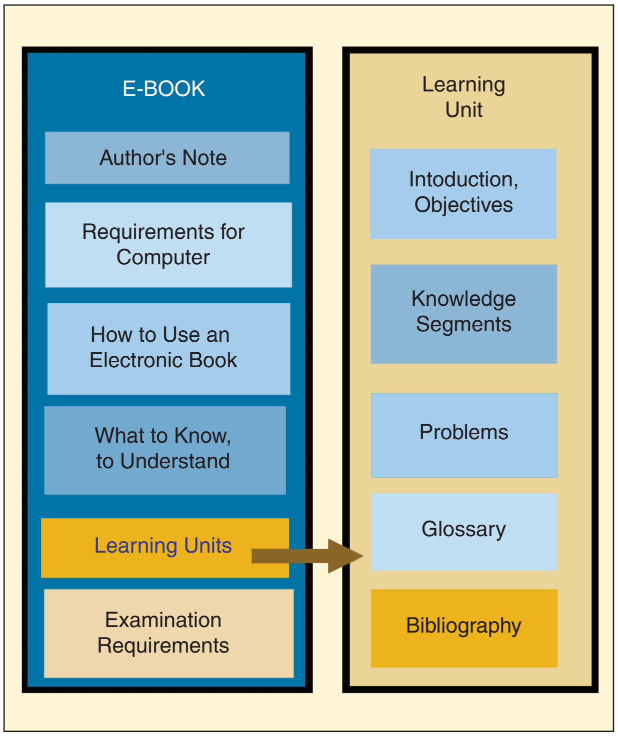

Fig. 1. Structure of the electronic book.

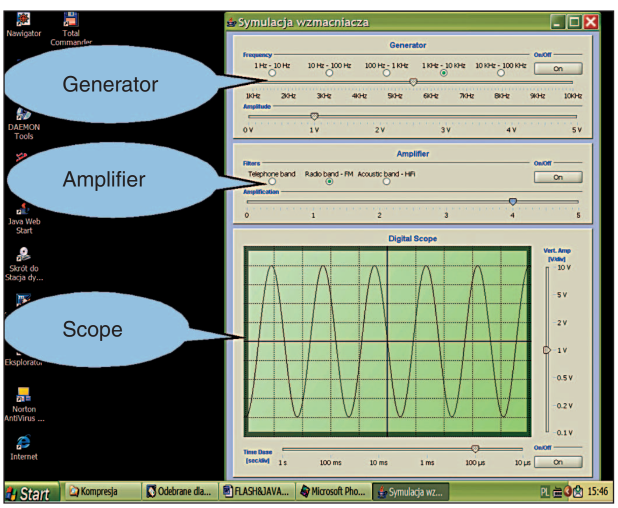

Fig. 2. The set of instruments prepared in Java applet form.

- solving tasks and problems
- writing reports and projects
- online meetings
- discussion with lecturers and other students.

A textbook is still one of the most important factors in this new concept of education. Thanks to the new ICT tools, the new version of textbooks used in distance learning is much more flexible and creative than traditional ones. This kind of book is known as an e-book.

E-Books

The didactic materials of the particular courses in instrumentation and measurement can be prepared by professors and experienced lecturers in the form of electronic lectures (books) and stored on CD-ROM. The same content can be placed on the Web sites, available via the Internet. E-books have the advantage of presenting all of the material of a single subject on one CD. The cost of multiplying it is relatively low, and creation of the material can be done with the dynamic HTML technology (HTML, cascading style sheets, Java script, and FrontPage tools). Because of nearly unlimited space, traditional educational content can be augmented with

- auxiliary software
- set of publications and source readings
- addresses and links to other knowledge sources: e-libraries, archives, collections
- questions and answers and tests
- animations
- simulations of experiments.

The material of an e-book should be divided into three main parts: introduction, learning units, and exam requirements [2].

The introduction should include:

- *Authors' note:* the authors describe the course objectives and explain what level of knowledge and what skills are expected from students after examining all the materials presented in the book.
- *Requirements:* requirements for the computer that will be used for the course.
- *How to use an e-book*: a clear, step-by-step instruction of how to use the material stored on the CD-ROM.
- *What to know and understand*: the authors explain what knowledge base is necessary to understand the didactic materials.

The learning unit should include a series of basic didactic parts that should be learned in a suggested order. Every learning unit is composed of several basic elements.

- *Introduction:* the aim of the particular unit
- *Knowledge segments:* basic didactic material that will be required from the students
- *Problems:* examples of partly solved problems and tasks to be finished by the student
- *Glossary:* new terms and definitions
- *Bibliography:* a list of important publications for further reading.

The exam requirements unit should be included only if the given course ends with an examination.

A proposed structure of the e-book is presented in Figure 1 [2]. The tools that can be implemented in the creation of an e-book can be divided into three categories.

Traditional tools
- texts
- fonts (bold, italic, and color)
- equations
- drawings
- photos
- background color and texture.

Multimedia tools
- text comments
- audio comments
- video comments
- animation of drawings
- animation of presentations.

Advanced tools
- generators of tests, local simulations, and distance simulations
- simulated experiments
- remote experiments.

Additional tools compatible to HTML
- Java applets
- FLASH modules.

The Java programming language plays a very important role in preparing multimedia applications. It is a very useful tool in writing network applications, and it can run under any operating system. Java applets can be introduced into an HTML text of any e-book. Java is able to enrich multimedia content of Web sites through animations, advanced graphics, sounds, and images. A very complex program can be distributed throughout the polymorphic network. An example of a Java applet is presented in Figure 2. The set of instruments, connected together, creates a measurement system to investigate an amplifier frequency response. We can change the amplifier frequency band from telephone to acoustic hi-fi. The frequency response can be investigated manually.

The second tool in the area of animation on Web sites is FLASH from Macromedia. It generates small files, acceptable to all Web site browsers. The FLASH format, with the .swf extension, is based on the vector graphic, where instead of keeping information about image pixels, like in .bmp files, mathematical formulas are used, describing shape, color, and layout of the object. The file takes up less memory and even complex animations are available to the viewer very quickly. The implementation of FLASH animation is a very simple process and available to everyone. An example is presented in Figure 3.

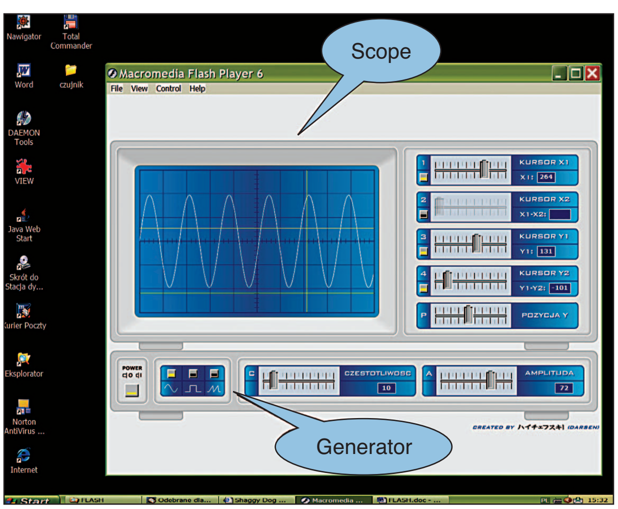

Fig. 3. An example of the FLASH animation module.

We can see two instruments on the monitor screen, a function generator on the bottom and a scope on the top, which are connected. The output signal from the generator can be seen on the scope display. This simulation is an example of a virtual instrument (VI) [5].

The VI Concept

To construct a VI, it is necessary to combine the hardware and software elements that perform the data acquisition and control, data processing, and data presentation in a different way to take maximum advantage of the PC. A VI is described as "a layer of software and/or hardware added to a general-purpose computer in such a fashion that users can interact with the computer as though it were their own custom-designed traditional electronic instrument" [10]. The concept for VIs is presented in Figure 4. In the future, instruments will move more and more from hardware to software.

The main categories of VIs are as follows:
- computer controlling GPIB or RS232 instruments with a graphical front panel on the computer screen to control the instrument
- plug-in DAQ board or a VXI module instead of an external instrument with a graphical front panel on the computer screen to control the instrument
- graphical front panel with no physical instruments at all connected to the computer. Instead, the computer acquires and analyzes data from files or from other computers on a network; it may even calculate its data mathematically to simulate a physical process or event rather than acquiring actual real-world data. This

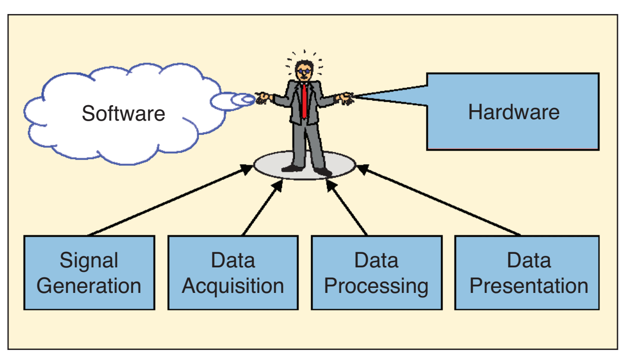

Fig. 4. The concept for VIs.

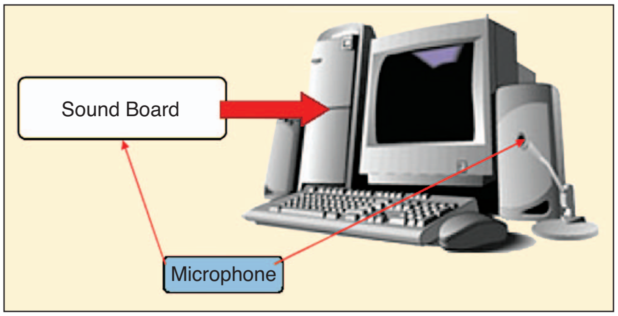

Fig. 5. Block diagram of spectrum analyzer based on Sound Board.

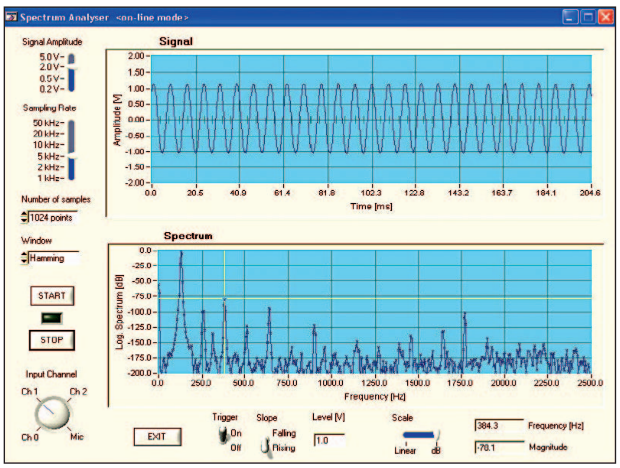

Fig. 6. Control panel of spectrum analyzer in online mode.

attribute can be used in e-books. It simply lets us create VIs, which can be placed on the CD. They can be prepared in HTML format or as a Windows application.

VIs are very beneficial because they enhance traditional instrument function, open the architecture of instruments, and promote widespread recognition and adoption of VI software development.

The following run VI techniques:

- *Operating systems*: DOS, Windows, X Windows, Windows NT, Unix
- *Processors*: 386, 486, 486DX2, Pentium, Sun Workstation
- *Buses*: PC, EISA, ISA, PCI, PCMCIA
- *Programming languages*: BASIC, C, C++.

Currently, the most popular way of programming VIs is based on high-level tool software. With easy-to-use integrated development tools, design engineers can quickly create, configure, and display measurements in a user-friendly format during product design and verification. The most popular software are the following:

- *LabVIEW* (National Instruments): A highly productive graphical programming language for building data acquisition and instrumentation systems (VIs). To specify a system function, block diagrams are intuitively assembled, a natural design notation for engineers. Its tight integration with measurement hardware allows data acquisition, analysis, and presentation solutions.
- *LabWindows/CVI* (National Instruments): A Windows-based, interactive ANSI C programming environment designed for building VI applications. It has a drag-and-drop editor for building user interfaces, a complete ANSI C environment for building test program logic, and a collection of automated code generation tools and utilities for building automated test systems and monitoring applications or laboratory experiments.
- *HP Visual Engineering Environment (VEE)* (Hewlett-Packard): An iconic programming language for solving engineering problems. It also gives the ability to gather, analyze, and display data without conventional (text-based) programming.
- *TestPoint* (Keithley): A Windows-based, object-oriented software package that contains extensive GPIB instrument and DAQ board support. It contains a novel, state-of-the-art user interface that is easy to use. Objects, called stocks, are selected and dragged with a mouse to a work area (panel). Logic flow is easily established with a point and drag action list. TestPoint takes advantage of Microsoft Windows features including DLLs for extendibility, bidirectional dynamic data exchange (DDE) for data exchange to and from other software, and Windows-style interface conventions.

The power of the tool software lies in libraries. Library functions enable:

- access to instrument interfaces (GPIB, RS-232, VXI, and DAQ)
- full control of autonomic instruments (instrument library)
- creation of GUI (graphics library, user interface library, formatting, and I/O library)
- digital signal processing (DSP) (advanced analysis library)
- access to a global computer network Internet (TCP/IP, DataSocket, ActiveX)
- interprocess data exchange DDE.

The ideal tool that enables easy control of programmable instruments is a specialized command set called the standard commands for programmable instruments (SCPI). SCPI dramatically decreases development time and increases readability of test programs. It has its own set of required common commands in addition to the mandatory IEEE 488.2 common commands and queries. Although IEEE 488.2 is used as its basis, SCPI defines programming commands that we can use with any type of hardware or communication link. It has an open structure. The SCPI Consortium continues to add commands and functionality to the SCPI standard. For example, the following command programs a digital multimeter to configure itself to make an AC voltage measurement on a signal of 15 V, with a 0.005 resolution:

```
:MEASure:VOLTage:AC? 15, 0.005
```

More Examples of VIs

A dual channel spectrum analyzer provides a very impressive example of a VI. The block diagram of a spectrum analyzer in Figure 5 was designed for a class. It is a "home version" based on a PC equipped with a typical sound board. Nearly all types of tool software are equipped with a soundboard so an expensive DAQ can be bypassed.

In the case of DAQ implementation, the software has been written under a LabWindows/CVI environment so that the GUI, or control panel, has a user-friendly form. It is divided into three separate parts. Each part includes a different control panel. The user can select the most appropriate to the specific measuring or analysis function. It is also possible to build a hierarchical structure of control panels. A control panel designed for both signal and spectrum presentation in the online mode is presented in Figure 6.

Furthermore, a user can select two different control panels for the offline mode: control panel for signal presentation (Figure 7) and control panel for spectrum presentation (Figure 8).

An example reconstruction of cooperative real instruments (function generator Agilent 33120A and digital multimeter Agilent 34401A) prepared under LabWindows/CVI is presented in Figure 9.

One of the most natural environments for VIs is a distributed system, especially in distance learning.

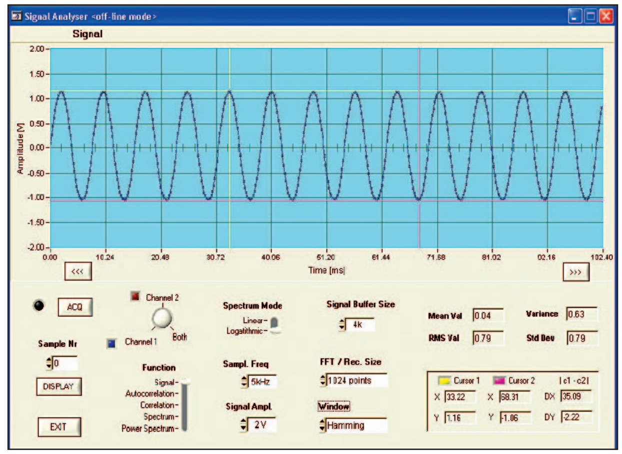

Fig. 7. Control panel of spectrum analyzer in offline mode for signal presentation.

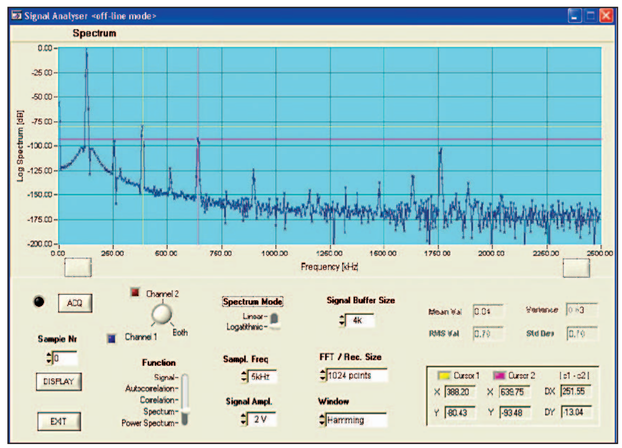

Fig. 8. Control panel of spectrum analyzer in offline mode for spectrum presentation.

Distributed Systems

A local area network (LAN) can be considered as a kind of measurement bus from the viewpoint of measurement and control systems. A typical example of such a system, including various VIs, is presented in Figure 10. It can be considered as a first step to a wider, Internet-based technology [9].

Common Internet-based software can be used to provide easy data migration between the various communication pathways. Multicomputer processing systems are effective in creating complex systems by overcoming the limitations of a single computer concerned with the overall computing power or the number of signals to be acquired and processed.

Standard software languages such as C and Java can be used with off-the-shelf development tools to implement the embedded network node applications and the Web-based applications, respectively. Internet-based TCP/IP protocols, Ethernet technology, and DataSockets can be used to design the networking infrastructure (Figure 11).

DataSocket is a software technology for Windows that makes sharing all measurements across a network (remote Web and FTP sites) as easy as writing information to a file. It uses URLs to address data in the same way we use URL in a Web browser to specify Web pages. DataSocket included with any software tool is ideal when someone wants to have complete control over the distribution of the measurements but does not want to learn the intricacies of the TCP/IP data transfer protocols.

In all the types of networked and distributed measurement systems presented previously, real-time operation and constraints are critical issues to be considered during system design to ensure the correct system operation.

Virtual Laboratory

The critical element of testing theory through experiments should be included in the distance-learning model. The virtual laboratory is the missing link in the ability to carry out physical experiments over the Web fully integrated with other media for delivering classroom content worldwide. In addition to simulating a virtual experiment, the reality of science and engineering can be learned better by remotely controlling an actual physical experiment. By supplementing classroom teaching with Web-based experiments, the student would be able to interact with physical systems under computer control. Laboratories accessible from the Internet provide enrichment to the educational experience that is hard to obtain from other video-based remote teaching methodologies.

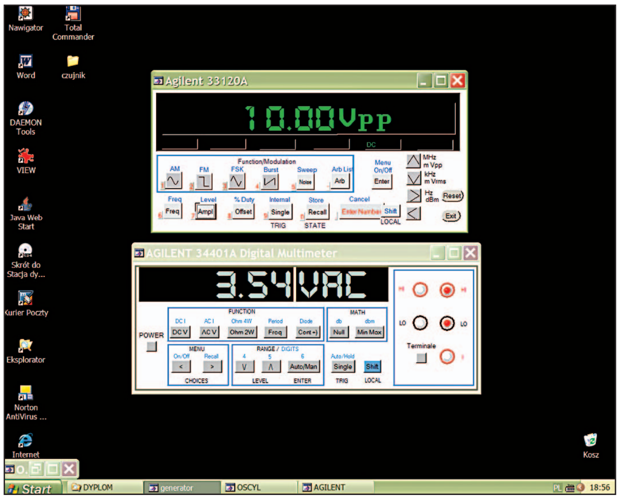

Fig. 9. The front panel of real instrument: function generator Agilent 33120A and digital multimeter Agilent 34401A.

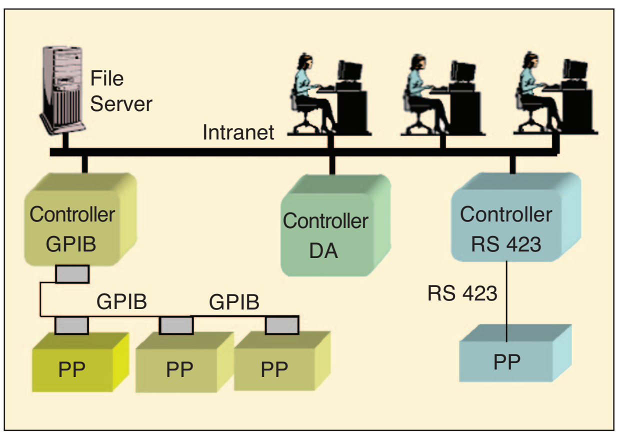

Fig. 10. Block diagram of distributed measurement system based on a local network.

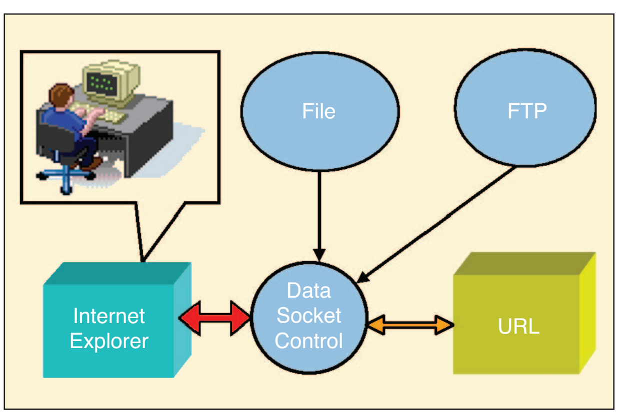

Fig. 11. The architecture of a distributed system based on the Internet.

Remote control of experiments and equipment over the Web is an idea that is just being explored. Different tools are now becoming available for remote control of instrumentation using network communication. Several demonstrations of camera control and data acquisition as well as simple experiments have already been made [1], [6]. Our knowledge concerning processes resulting from experiments, ability to control these processes, and a set of tools needed for digital recording and transmission are good enough to introduce a new model of laboratory research called a virtual laboratory. The most important elements of a virtual laboratory are VIs and distributed measurement systems. The idea of a virtual laboratory is presented in Figure 12 [8].

Let us imagine that a research center offers in a LAN some selected resources. All the researchers, scholars, and students have limited access to this environment. After connecting the local center to the Internet, the offered instruments also can be used by the students from outside. The resources can certainly be shared in much wider scale. It is very important in the case of very specialized, expensive equipment.

The software designated for system supervision should implement the following tasks:

- communication process (between user and laboratory)
- access to laboratory resources (systems, instruments, and functions)
- management over the laboratory resources (single instruments or groups)
- organization of the users (groups, rights to resources, rights under conditions, changes of rights, and priorities)
- control over the single users and groups (authentication: password, authorization: rights).

The measurements can be realized in two modes: on demand and online. The first mode includes two separate cycles: query and answer. In the online mode, the user has constant access to the instrument (online selection of functions and parameters, watching results).

Software must include two main parts: server application and client application. Each client includes a control panel of virtual scope, prepared especially for running tests. The client can be attached to a server, a gateway to real instruments. After login, a session opens for programming instruments and receiving measured data. Additionally, the server plays a role of rights control, security carefulness, and much more (concurrency of processes and multiaccess).

Certainly, the most important use of a virtual laboratory is for distance learning. Online experiments can possibly have an effect on a real process or object. The advantages of a virtual laboratory are exposed in quite a number of papers.

Distance Learning at WUT

Three years ago, WUT authorities agreed it was time the WUT develop and adapt a new model of studies [3]. The Internet and multimedia have become the basic tools of a new model of education, known as SPrINT (short in Polish for Studia Przez INTernet).

The introduction of an entirely new model of studies by the WUT, a university with 30,000 students enrolled in 18 faculties, was implemented by the establishment of a new university unit, Center of Open and Distance Education (CODE); in Polish, Osrodek Ksztascenia na Odleglosc (OKNO) [11]. The Director of CODE, Prof. Bogdan Galwas is a rector's delegate for the implementation of the new technologies in education and is responsible for all events associated with distance learning.

CODE does not have full-time academic teachers. The lecturers of the particular faculties are responsible for the creation of didactic materials, student supervision, and conducting examinations. The four-year studies lead to a B.Sc. degree in engineering with a chosen faculty and specialization. The academic year is divided into four quarters, autumn, winter, spring, and summer, and enables students to study no more than two subjects at the same time. Each quarter lasts eight weeks and finishes with two weekend sessions for examination. During the summer vacations, laboratory training is introduced.

The grading of the subjects is based on the credit points system (cps), used in the university teaching systems by the majority of European countries. The credit system gives students the opportunity to gather credit points. The total number of credits for the subjects is 248.

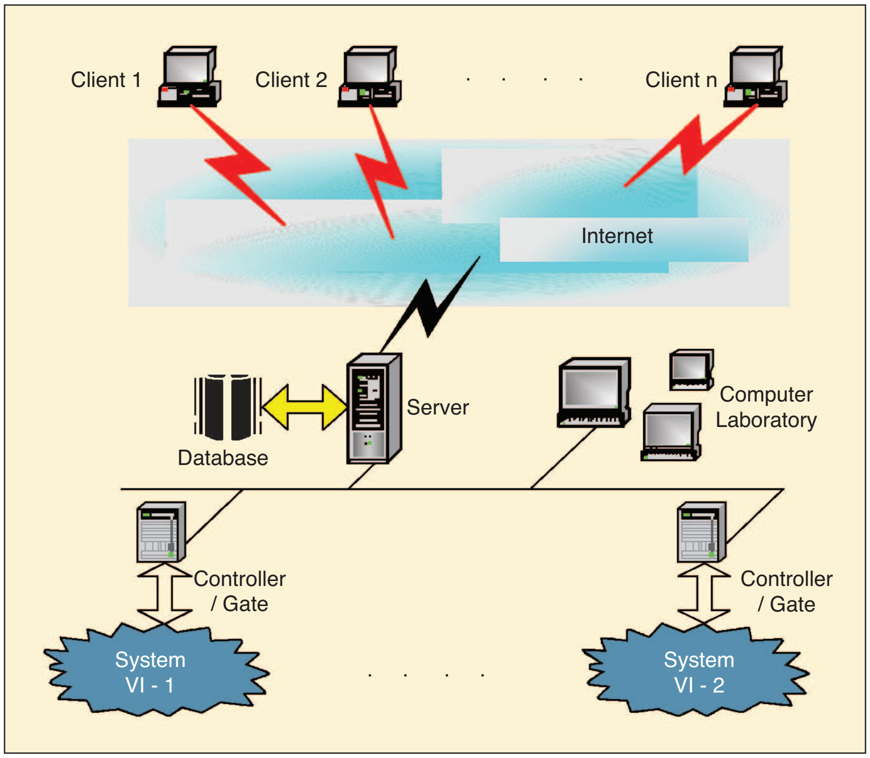

Fig. 12. The virtual laboratory.

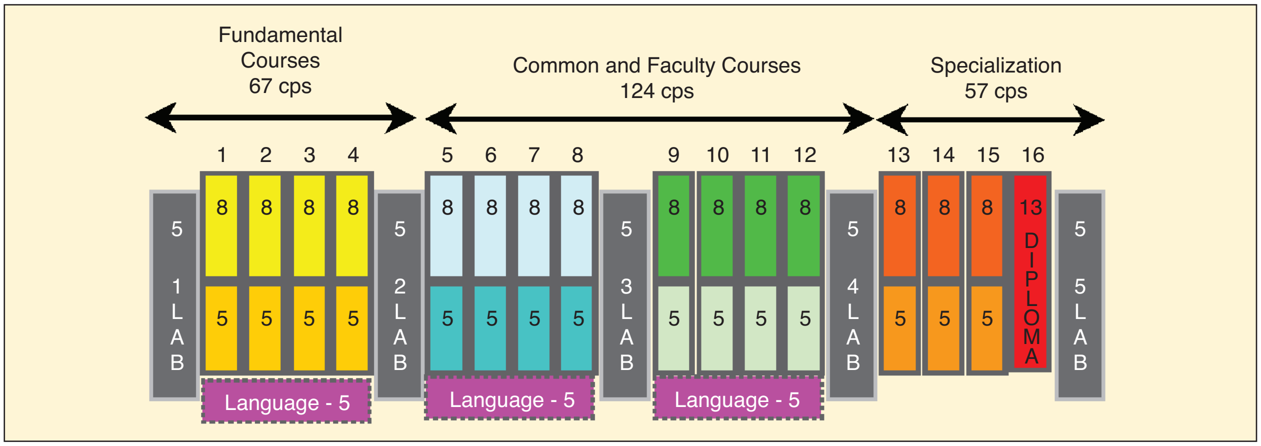

Fig. 13. The structure of the SPrINT model.

A three-level system of studies is obligatory.

- *One-year fundamental courses:* The program is fairly basic and universal; a student is required to credit four major courses, four minor courses, and two laboratory sessions, for 67 cps.
- *Two-year faculty courses:* This program is dependent on the faculty chosen; a student is required to credit eight major courses, eight minor courses, two laboratory sessions, and a language course, for 124 cps.
- *One-year specialization courses:* Each faculty can offer more than one specialization; the student is required to credit three major courses and three minor courses and complete a diploma thesis, for 57 cps.

Figure 13 shows the structure of the SPrINT model.

The three faculties of the WUT, Electrical, Electronics and Information Technology, and Mechatronics, offer courses in the following specializations:

- applied informatics (Faculty of Electrical Engineering)
- computer engineering (Faculty of Electronics and Information Technology)
- multimedia (Faculty of Electronics and Information Technology and Faculty of Mechatronics)
- mechatronics (Faculty of Mechatronics).

The structure of the studies program offered by three faculties is presented in Figure 14.

The fundamental courses offered during the first year of studies (mathematics, physics, basics of computer engineering) are universal for the three faculties and can be accepted by nearly every faculty of the WUT. The fundamentals of electrical, electronics, and mechanical engineering offer a set of courses for the second and third years of studies. There are a large number of common courses for each faculty. During the fourth year, students attend only courses of their specialization and complete their final B.Sc. diploma thesis.

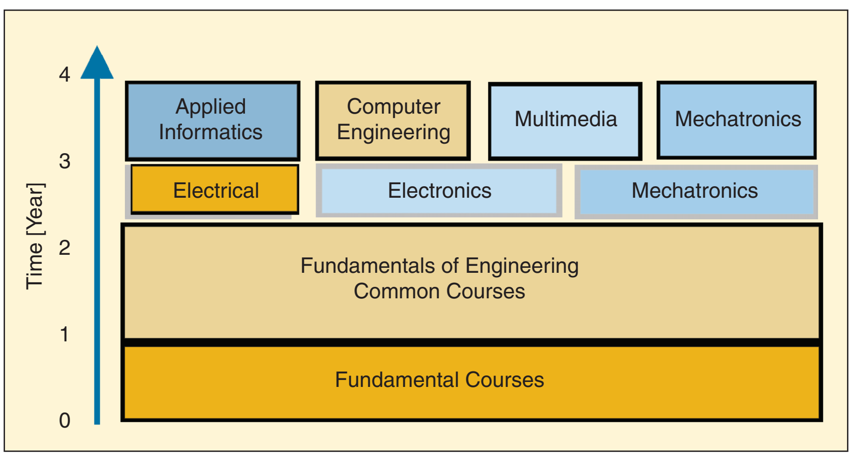

Fig. 14. The structure for the program of study.

Conclusions

As soon as the WUT authorities approved the new model and program of engineering studies, a group of specialists and tutors started the creation of new e-books. A group of computer scientists, with the help of Lotus LearningSpace software platform, prepared an educational portal OKNO. These e-books are in the Polish language.

Instrumentation and measurement is also introduced into the described model. This lecture is common for all students from three faculties. Information and measurement systems is a subject in the applied informatics curriculum. Both subjects have individual e-books, which are enriched with a simulation of experiments.

In October 2001, 200 students enrolled and started education in a new Web-based model of undergraduate engineering studies. Approximately the same number of students have started every year since then. In September 2005, we will have the first graduates. In October 2005, we will start a complementary two-year program of studies leading to M.Sc. degree, following the same format.

The new model of studies can always be improved and developed as new technology becomes available. Thus, one of our objectives is to develop and enrich the model with a set of new multimedia tools, e.g., preparing lectures on DVD, designing new simulation tools, and installing advanced software accessible throughout the Internet. Improvements in the area of remote access to laboratories have the highest priority in the instrumentation and measurement branch of distance education. It is a very useful tool for teaching purposes in distance learning. Students can access VIs via a geographic network and directly carry out real experiments by the using of a simple standard commercial Internet Web browser. In this way, a more complete educational proposal can be offered by several laboratories specialized in different measuring fields. The remote laboratory concept allows measuring resources located at different geographically remote sites to be utilized by a wide distribution of students.

Another objective for the future is the establishment of a network of universities offering distance education. In Poland, seven technical universities participate in a common project entitled “Politechnika Wirtualna” (in polish Virtual Technical University).

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my favorite experiment *continued from page 60*

Give It a Try

I really enjoyed building this pendulum. It was both fun and educational and helped drive home one of the invisible mechanisms causing me trouble at work. I also believe it would make an excellent science fair project for a budding young scientist and a parental engineer, that is as long as you don't live on the equator where infinity can be a long time to wait for signs of a rotation. Although, if you do live on the equator, it should be possible to excite a vibrating rod in a horizontal plane and watch it precess around like a bicycle wheel over a standard sidereal day.

If you decide to give this pendulum experiment a try with your son or daughter, let me know. I'd like to see if they come to the same conclusions as I did, especially if you happen to live in the Southern hemisphere.

Lastly, if you do happen to reside in the Southern hemisphere and have a school age son or daughter interested in science, drop me a line. I'm looking for someone to help out with a future "My Favorite Experiment" dealing with the Coriolis effects, and I need the assistance of a young scientist who lives south of the equator to run a few experiments and share a byline. Locating a second young scientist who lives on the equator would be icing on the cake!

Reference

[1] J. Witzel, "Charge transfer based sensing," *IEEE Instrum. Meas. Mag.*, vol. 3, no. 3, pp. 54–56, 2000.

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