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REMOTE LABORATORIES EVOLUTION

T. Vince, R. Balvirčák
Technical University of Košice
vul. Letná, 9, Košice, 042 00, Slovak Republic. E-mail: tibor.vince@tuke.sk, rudolf.balvircak@student.tuke.sk

This article describes problematic of remote laboratories, history and evolution steps of remote laboratories. During last decades expansion and evolving of IT technologies brings new opportunities also to education and industrial field. One of the new opportunities is also worldwide range monitoring and controlling, distance education etc. There are many developers for simulation software supporting electric circuit simulations. Software simulation is not as effective as real experiments. Teaching electrical engineering requires mostly laboratory work mandatory. Remote laboratories allow execute real experiments also remotely, could offer all the advantages of the new technology.

Key words: remote laboratories, education, electrical measurement.

РОЗВИТОК ЛАБОРАТОРІЙ ДЛЯ ДИСТАНЦІЙНОГО НАВЧАННЯ

Т. Вінсе, Р. Балвірчак
Технічний університет Кошице
вул. Лєтна, 9, Кошице, 042 00, Словаччина. E-mail: tibor.vince@tuke.sk, rudolf.balvircak@student.tuke.sk

Освітлено проблематику віддалених лабораторій, історію їх розвитку й основні кроки еволюції. Останні десятиліття розповсюдження та розвиток інформаційних технологій надає нові можливості також в освітніх і виробничих сферах. Однією з новітніх переваг є можливість здійснення моніторингу та керування роботою обладнання з будь-якої точки планети, можливість дистанційного навчання та ін. На сьогодні існує багато розробок програмного забезпечення для моделювання з можливістю моделювання електричних кіл. Проте комп’ютерне моделювання не є настільки ж ефективним, як проведення реальних експериментів. Навчання електромеханіці вимагає в основному практичної роботи в лабораторії. Дистанційні лабораторії дозволяють виконувати реальні експерименти віддалено та можуть запропонувати всі переваги новітніх технологій.

Ключові слова: дистанційні лабораторії, освіта, електричні вимірювання.

INTRODUCTION. Laboratory experiences are part of the educational process in most of the engineering studies. Especially in electrical engineering is laboratory work mandatory. Engineering laboratory environment provides students with opportunities: to test conceptual knowledge, to work collaboratively, to interact with equipment, to learn by trial and error and to perform analysis on experimental data [1].

The rapid progress of Internet and computer technology, along with its increasing popularity, enables the development of remote laboratories for supporting distance laboratory courses, where the experiments can be accessed, monitored and controlled remotely [2]. New technologies in training procedure enable the students to interact with the laboratory at any time, decrease experiment cost per student. Remote laboratories offer higher level experimental training if they support and interact with real lab experiments compared to the simulations or simple presentation of the reality.

This paper is focused on electrical measurement remote laboratories.

EXPERIMENTAL PART AND RESULTS OBTAINED.

Measurement laboratories

Measurement can be defined as a set of actions or a procedure necessary to determine the value of a physical quantity. In metrology there has always been a trend to improve accuracy and lower the cost of measurements. IT technologies are often involved in modern measurement methods. With evolution of these methods, “remote” and “computer supported” laboratories were implemented. In this bachelor thesis, matters about distance-driven laboratories worldwide are discussed, with focus on those performing measurements of electrical physical quantities [3].

In order to understand the basic concept and differences between various types of laboratories, we need to divide them into three main groups [1]:

– Standard laboratories;
– Pure virtual laboratories;
– Remote laboratories.

Standard laboratories represent real laboratories controlled and supported by educated academic staff. Usage of such laboratories is based on physical interaction between the measurer and the measurement system. These contain measured objects and measuring devices at one place and can be represented by for example scientific research laboratories or didactic laboratories at universities. Such laboratories are based on collaboration of more users at one place, for instance more scientists working together in one laboratory or a lecturer teaching students about measurement of electrical voltage. And also due to this fact standard laboratories are less safe in terms of occupational health and safety compared to virtual and remote laboratories. Standard laboratories are also considered high-cost, as hardware resources need to increment with increasing number of users.

Pure virtual laboratories are designed to simulate conditions of a real laboratory environment. These laboratories do not contain any physical objects except from a computer, but are represented by software, thus are considered as low-cost compared to standard laboratories. The software varies depending on its use and creator. Examples of such laboratories are computer programs like OrCAD with PSpice or MATLAB and Simulink. OrCAD is a software that lets users to create custom electric parts and circuits, measure electrical voltage, current or power and display signals using PSpice simulation environment. Example of virtual laboratory interface is shown on Fig. 1.

The most striking difference between pure virtual, standard and *remote laboratories* is that pure virtual laboratories return idealized values of measured physical quantities of subjects. Virtual laboratories are also considered a poor substitute for standard laboratories due to the absence of measuring hardware.

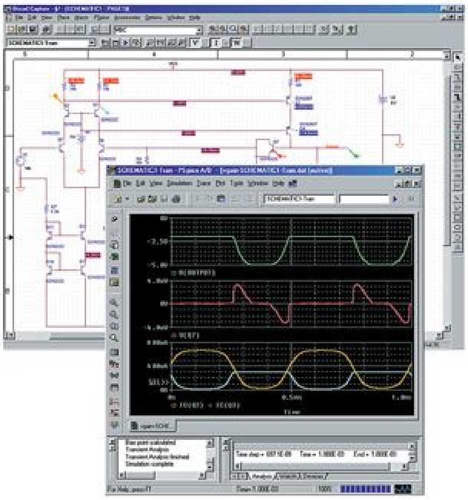

Figure 1 – Virtual laboratory environment

Remote laboratories. The "*remote laboratories*" (or "distance-driven laboratories") refers to a set of hardware and software used to perform measurements controlled remotely, over geographical distance and with the ability to return (or display) measured data to users using communication networks.

Modern remote laboratories are based on the client/server network structure. The client asks the listening server for data and the server answers. This is the only structure which assures user-friendly usage of these systems, because clients acquire information only when they need it. However, implementation of the peer-to-peer structure is not used in this area.

By comparing over 50 remote laboratories worldwide and considering similarities between these, a most of the remote laboratories consists of five objects [3]:

1. The experiment (for example investigating the time of oscillation of a pendulum or a measurement of resistor's resistance). In fully-modifiable remote laboratories (which are discussed later in this work), experiment can be represented by components connected to a relay switching matrix.
2. Laboratory's instrumentation – this contains measuring devices and power sources located in the laboratory.
3. A web server handling user queries and providing the remote laboratory with client side environment.
4. A laboratory server computer controlling the ongoing experiment and returning data to web server.
5. Software designed and optimized for a specific laboratory providing suitable graphical user interface (GUI), either running on a web server (using HTML webpages as interface) or on a client's computer (represented by computer software interface).

Diagram of the above-described structure is illustrated in Fig. 2

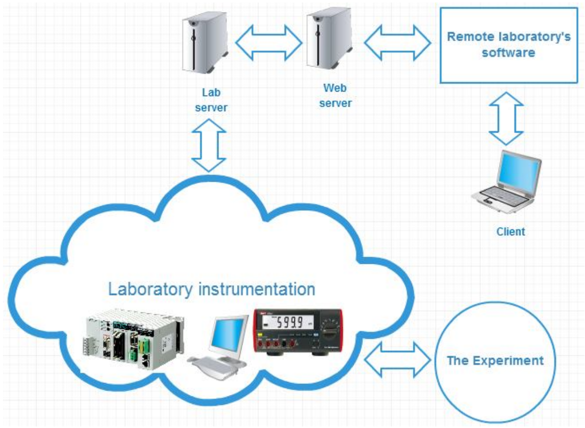

Figure 2 – Common remote laboratory principle structure

There can be slight modifications, like extra user management, video streaming or database servers. Overall, the principles remain the same.

Some of the remote laboratories perform calculations centrally and are able to handle multiple connected users almost simultaneously. That means one circuit or a measuring device is available to more students at in one moment. An example structure of a multiple users remote laboratory is described in Fig. 3.

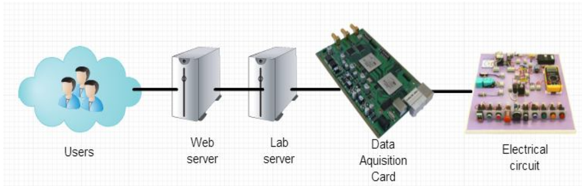

Figure 3 – Multiuser remote laboratory principle structure

There could be multiple purposes for remote laboratories. The main purposes usually are:

- Didactic;
- Scientific;
- Industrial.

Didactic remote laboratories are laboratories primarily used for educational purposes. These are supervised by academic staff and serve as educational tools in engineering high schools and universities. Such laboratories are mainly accessed by lecturers and students.

Scientific remote laboratories are used for scientific purpose. In such laboratories are used specific custom devices for multiple users or the laboratory itself is located in difficult allowable place. From a certain point of view can be considered as a scientific remote laboratory for instance robotic rover Curiosity on Mars.

Industrial remote laboratories include measuring systems mainly in the industry area, for example a substation with a measuring system returning data about voltage transformers or SCADA systems for remote control in industry.

In our research we focused on modern electrical didactic remote laboratories. These laboratories mainly provide educational environment for their users, as well as a quick way to measure parameters of specific objects remotely.

Remote laboratories publications

According to [4], number of publications about remote laboratories peaked around 2002 and 2003, as it is apparent from Fig. 4, however, the term "remote laboratories" or "virtual laboratories" appeared in scientific publications in the 1990s. According to the scientific area of research done in [4], remote laboratories mostly appeared in electronics and robotics. The author took 42 remote laboratory subjects into account.

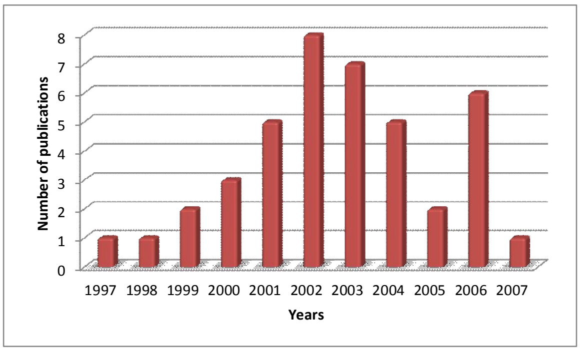

Figure 4 – Remote laboratories publication repartition by year in [4]

Remote laboratories (or more precisely their variations) first appeared in industrial implementations. From this point of view, the exact year of the start of their evolution is questionable. Remote measuring, in older literature often called "remote metering" or "telemetry", appears in industry as a part of electrified measuring system providing the complex system with connectivity and controllability of specific electrical circuitry. A fitting example of remote industrial measurement can be the "Supervisory control and remote metering installations on the electrified section of the Pennsylvania Railroad", described in [5]. The article about this project was published in 1936, which suggests that research of remote measuring was influenced by industrial revolution. Figure from the project is shown in Fig. 5.

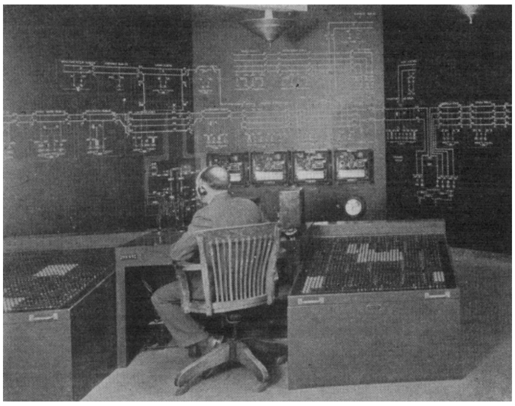

Figure 5 – Total load telemetering recorders in front of dispatcher's desk

Internet history dates back to the year 1962 [6]. So remote measuring and remote controlling begins before Internet itself.

As said earlier, modern remote measurement laboratories peaked around 2002. One of the first modern remote laboratories before this era can be found in [7] and was implemented in 1993 in the University of North Carolina at Charlotte. The laboratory itself is a system of laboratory equipment accessible by a number of client workstations. Interestingly, users are connected to laboratory's environment by a local area network (or LAN) and not by the Internet network. The structure of such laboratory is illustrated in Fig. 6. The laboratory provides students with experiments (such as measuring the scanning frequency of a vibration analyzer) and a user-friendly interface of the software. The software mentioned is an implementation of the X-Windows toolkit, and is coded in C. One of the software's main functionalities also includes connecting and disconnecting to the server PC. The server PC handles the requests and places them into a queue, thus an experiment scheduler module is needed to operate with the data.

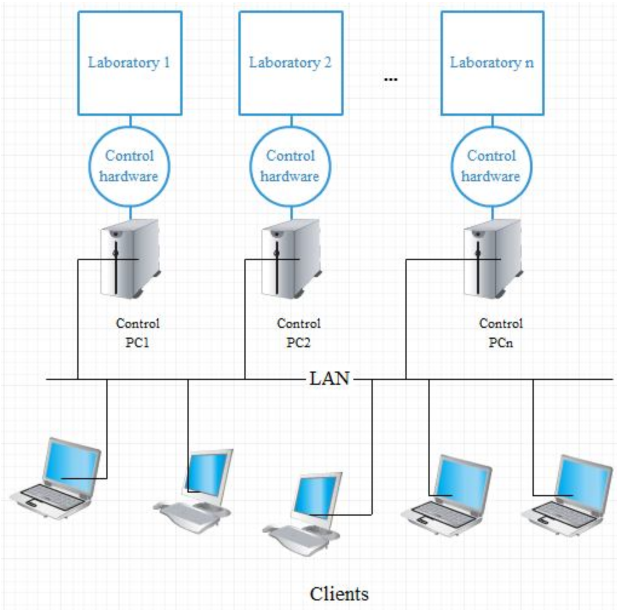

Figure 6 – Structure of University of North Carolina at Charlotte remote laboratory

Although no visualization of the ongoing experiment is provided in the user interface, it can be implemented using a camera as said in [7]. The user interface is still able to display the plots of physical quantities and this increases the quality of the didactic process.

Remote laboratories evolution

Compared to the remote laboratory at the University of North Carolina at Charlotte described above, another of the evolution steps in didactic remote measurement was the laboratory system of Case Western Reserver University (CWRU) described in [8]. The laboratory system was developed in 1998 and represents one of the modern didactic measurement laboratories for universities. The system operates with Macintosh computers connected to CWRU's network and uses the LabVIEW software as the user environment. The LabVIEW server uses Common Gateway Interface (CGI), which is a standard for interfacing external applications with information servers, such as HTTP or web servers. The system is based on a limited number of predefined experiments. The reason for this is the hardware heaviness of these experiments. For example, an experiment equipment simulating water flow system, where elements such as pumps or diverter valves can be controlled. This requires significant amount of hardware as well as sensors observing the water level and flow. Modifiability and interactivity of such systems is often considered more valuable when discussing didactic purposes. The experiment is also supported by looped refreshing of images of an ongoing process of the experiment.

Technical possibilities of remote laboratories evolved together with used technologies. Remote measurement laboratories may vary in modifiability level. According to the modifiability, we can divide remote laboratories to the following group:

– Non-modifiable;
– Half-modifiable;
– Fully-modifiable.

The term *non-modifiable* remote laboratories refers to laboratories where users on the client side are not able to modify any input values of the measurement. Users can only start a measurement and view the output values. These laboratories are used to determine the current status of an object. Remote laboratories measuring environment temperature or atmospheric pressure are a fitting example. Todays it is quite common and could be refer as telemetry.

Half-modifiable remote laboratories are laboratories with the ability for the user to change the input values of the measuring system; however, the user cannot freely add or remove the components of the measured system. This means the client is able to modify physical quantities (e.g. input value) and certain parameters of components of the measured system. Examples include moving valves, changing range or input values of measuring instruments or changing resistor's resistance from 220Ω to 1 kΩ.

Fully-modifiable remote laboratories are laboratories with the ability for the user to fully modify the measured system. The client is able to change the input as well as add or remove components of the system. Adding and removing the components is based on variable connections. Electrical relays are often used to supplement these features. For example, the client can build custom electrical circuits limited only by the set of available components and then perform measurements.

T describing the most current trends, it is a needed to mention some modern internet portals devoted to remote measurement laboratories. These portals contain associated databases merging more laboratories in one place. Two of these portals are demonstrated and characterized – GOLC and lab2go.

GOLC stands for Global Online Laboratory Consortium. It is focused on promoting the development, sharing and research of remotely accessible laboratories for educational use. GOLC's objective is to create a shareable experimental environment for its users. There are 17 universities worldwide involved in GOLC [9].

Lab2go is an interesting web repository cooperating with GOLC. It aims at bringing people involved in online labs together by offering a common web environment to share experience and knowledge. It provides space on the internet for laboratories worldwide to share data about their research [10].

The third thing to be mentioned is the VISIR project. VISIR or Virtual Instrument Systems in Reality is a project forming a group of cooperating partners creating software modules for online laboratories [11]. VISIR cooperates with many universities and with the National Instruments Corporation.

National Instruments (NI) is a company collaborating with scientists and engineers. It provides technical solutions and commercially sells hardware and software packages for engineers to use. NI also focuses on development of educational measuring hardware and software, which are widely used in current remote laboratories such as NI ELVIS package.

Hardware and interfaces used in remote laboratories

However, the variety of hardware is also caused by geographical location of laboratories, as some of the hardware producing companies are popular in certain countries.

Another factor is the large number of brand options as nowadays there are many different companies selling measuring hardware. Many laboratories are using oscilloscopes mainly from Agilent (nowdays Keysight Technologies), NI, Tektronix and Hameg.

GPIB (General Purpose Interface Bus, also known as IEEE 488) and RS232C interfaces are commonly used to connect measuring devices with laboratory (measurement) servers [12]. Many modern measuring devices have these built-in. The advantage of using RS232C is that it is present in modern computers. GPIB demands installation of additional hardware, which means higher cost. The disadvantage of RS232C is that it is used for one to one connection. GPIB can handle up to 16 devices on the bus. Another disadvantage of RS232C is that it is based on serial communication, which means it sends one bit after another and its data speed averages at 2kB/s. GPIB's parallel communication allows it to send multiple bits simultaneously and its data speeds are up to 3MB/s [12].

RS485 can be used instead of RS232 in order to get higher bandwidth and number of transmitters and receivers.

The I2C interface is also commonly used for interconnection of more integrated circuits (IC) used in laboratories.

Another specific devices used in remote laboratories are DAQ cards (Data acquisition cards) depicted in Fig. 7.

Figure 7 – The PXI – 6259 by National Instrument

In fully-modifiable remote laboratories, "relays switching" and "switching matrices" are fundamental terms. The most effective switch is an ideal switch. An ideal switch has these attributes [13]:

– R (resistance) = 0 when closed;
– R = ∞ when open;
– It is completely isolated from other switches;
– Is isolated from drive control circuit;
– Switching time T = 0.

Such conditions are obviously not possible in real switches.

There are several switch topologies. Fig. 8 depicts single pole single throw (SPST), single pole double throw (SPDT), double pole single throw (DPST) and double pole double throw (DPDT) topologies. NO is a normally open contact and NC is a normally closed contact.

Multiplex switching is used for connecting one input to multiple outputs (1:N) or one output to multiple inputs (N:1).

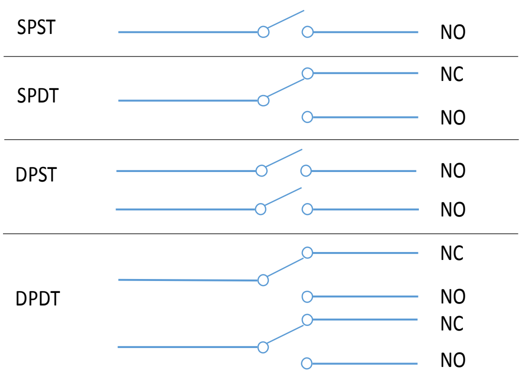

Figure 8 – Switch technologies

Matrix switching is really flexible and offers interconnection of multiple inputs and outputs. Relays form a matrix with M columns and N rows. Measuring devices and signal generators are at the M (rows) side. Measured objects (in literature these are usually called UUTs – units under test or DUTs – devices under test) are connected at the N (columns) side [13]. Fig. 9 illustrates a small 6x6 switching matrix. The small blue dots in the figure are called cross points. A cross point is depicted in the bottom left corner of the picture.

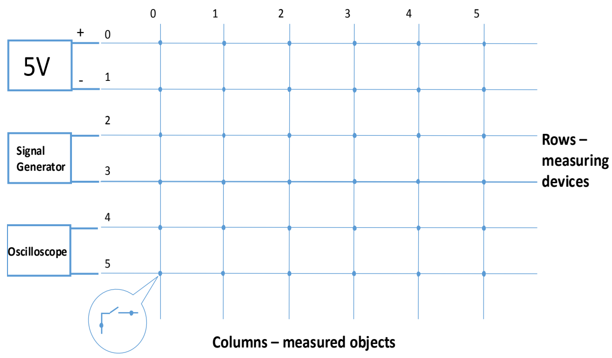

Figure 9 – Switch technologies

In real fully-modifiable remote laboratories, switching matrices are often divided into separate cards.

Software technologies and programming languages

Most of the remote laboratories use the internet network for user access. The HTTP, TCP, UDP and IP protocols are fundamentals of communication of devices over the internet. Users use either GUI of an installed software or web browsers to access the lab.

Nowadays, there is a great number of programming languages and the number is still rising. The client side GUI of a remote laboratory (either in a web browser or installed as an application on a device) as well as the server side (communication of server PC with lab's instrumentation) can be developed using many different programming languages.

Client applications can be developed using C, C++, C#, HTML, JavaScript, JSP, Java, PHP, Ruby, Perl, Python, ASP.NET and others.

The server side, however, is more delicate as it communicates directly with the laboratory. Graphical block programming language using the LabVIEW environment is commonly used. LabVIEW offers a software development kit capable of creating standalone applications. In LabVIEW, interaction of data is performed by professional GUI including graphs and 3D visualization.

The second programming approach used is object oriented programming applied in popular programming languages, such as C, C++, C# and Java.

The second approach is not limited by any elements or blocks that are used in LabVIEW. This adds more power to the programmer, meaning no creative boundaries and easier debugging.

This fact also means starting the coding from scratch, thus it needs more time to be done. This is where LabVIEW has the upper hand as an easy-to-use time-saving development framework.

Fully-modifiable remote laboratories

As written above, fully modifiable remote laboratories represent high evolution level of remote laboratories. In this chapter few remote such a fully-modifiable are described.

The *VMLab* (abbreviated form of "Vzdialene meracie laboratorium", which is Slovak for "remote measurement laboratory") is a remote laboratory located at the Department of Theoretical and Industrial Electrical Engineering (KTPE). The project means a novel approach in remote electrical measurement using switching relays. Its aim is to provide students with access to electrical measurement from any place connected to the internet. In VMLab, there are 16 connection lines and 64 switching cards in the current prototype (16 rows x 64 columns). Number of switching cards is equal to number of usable poles. Therefore, the system is now capable of connecting 32 dipole components. However, these limits can be expanded. The system uses UNI-T UT 803 multimeters, AC250K1D AC power sources, BK Precision 9122 DC power sources, Lutron DW-9020 power analyzer. Electrical power sources are configured to 1A limit, but connection lines used are able to handle up to 10A. GUI of the VMLab is shown in Fig. 10 [14].

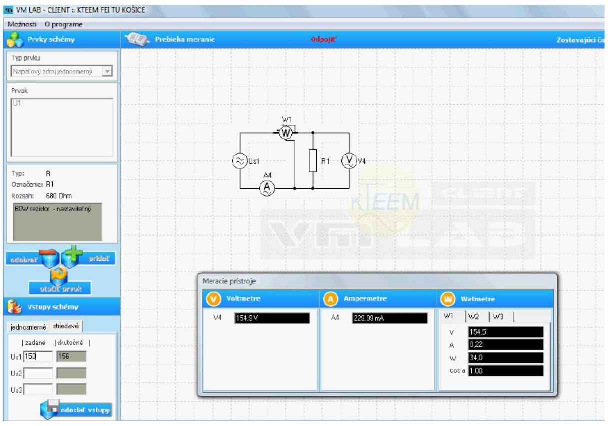

Figure 10 – VMLab GUI

The *NetLab* is used by undergraduate students to perform experiments on electrical circuits. The sentence above describes didactic aims of this measurement laboratory. The implementation was developed at University of South Australia (UniSA) in Adelaide. NetLab uses a single dedicated server (supported by Java and LabVIEW) to handle user queries and configure remote laboratory's instrumentation, however there is another server involved in streaming webcam video as well. By using the "Circuit Builder" GUI which is shown in Fig. 11, users are able to configure various custom circuits. Measured objects are represented by adjustable resistors, capacitors and inductors. Users can also use an Agilent 33120A, which is a 15 MHz function and arbitrary wave generator, Agilent 54624A 100 MHz four channel oscilloscope, Agilent 34401A digital multimeter and an in-house built linear 120:50 transformer. NetLab uses an Agilent E1465A 16x16 relay switch matrix which can be used up to 1A [15].

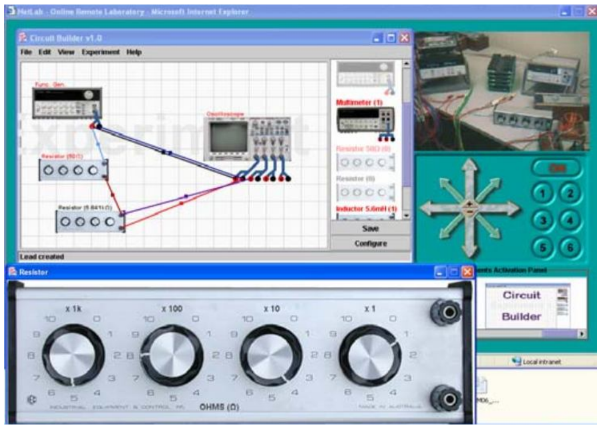

Figure 11 – NetLab GUI

An *RMCLab* (Internet-based Remotely Monitored and Controlled Laboratory) is represented by project implementation from the Department of Electrical and Computer Engineering, University of Patras Rion Campus, Greece. The Resource Server handles hardware instrumentation of the laboratory. The Application Server controls data between laboratory and a client and handles their requests. It works as a proxy server between Resource Server and clients. Circuits are designed in offline mode using MAX+PLUS II or Quartus and then loaded into the client app. When a client creates a request, he can either choose to measure preset or custom electrical circuitries. Clients can choose from components such as switches, variable capacitors, resistors, inductors, a variable power source and an oscilloscope [16].

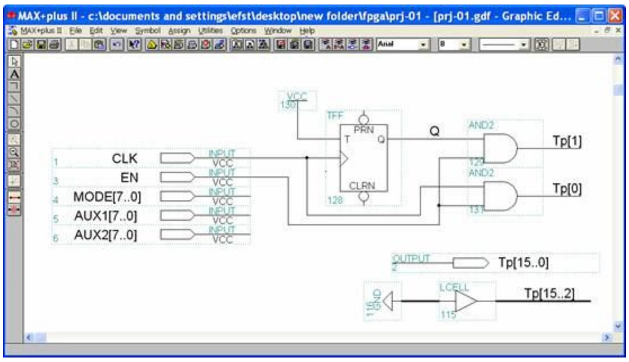

Figure 12 – RMCLab GUI

RWMLab, as abbreviated from Remote Wiring and Measurement Laboratory, is a web based laboratory aimed at real-time remote wiring of electrical circuits [17]. It has been developed at the Electrical and Computer Engineering Department of Western Michigan University. The client side uses a web interface (depicted in Fig. 13) for users to access the measurement. A virtual breadboard element was implemented allowing users to assemble custom electrical circuits of resistors, capacitors, transistors, operational amplifiers and diodes. Users are able to use DC and AC power sources, a function generator, a digital voltmeter and an oscilloscope. It is possible to modify parameters of laboratory's instrumentation. The GUI also includes a camera stream. On the server side, there is a server connected to a relay switching matrix and a complex programmable logic device (CPLD). The web server is an AMD 40 MHz AM186ESS-based microcontroller (Xecom's AWC86A). The matrix uses standard electronic relay latch components and is laid on a standard breadboard. It is used for interconnection components and instruments. Instruments are connected using a GPIB interface. Switching pattern of the matrix is controlled by the AWC86A through CPLD [17].

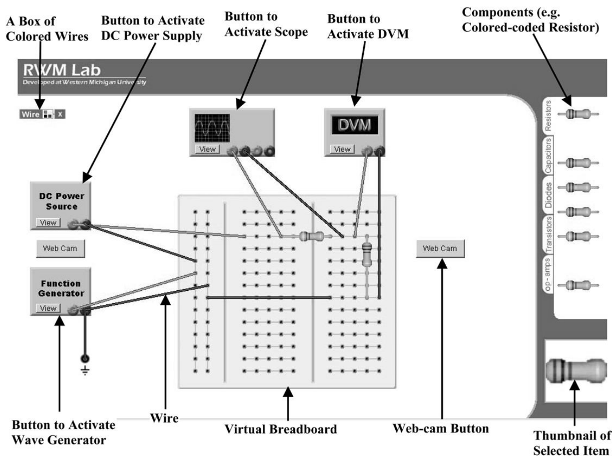

Figure 13 – RWMLab GIU

CONCLUSIONS. In this paper we presented history, technical evolution steps and described few remote laboratories highest evolutionary level now. Expansion and evolving of IT technologies extended education opportunities like e-Learning, also remote monitoring (telemetry) and remote controlling in industrial field become used in practice. E-Learning could be complicated, when laboratory work and experiments during the education are required [18–21]. This problem is typical for electrical engineering education. There is a large number of simulation software, but simulation can't replace real experiment and real measurement.

One of the possible solutions could be remote laboratory. The "remote laboratories" refers to a set of hardware and software used to perform measurements controlled remotely, over geographical distance and with the ability to return measured data to users using communication networks.

Evolution stage from technical point of view could divide remote laboratories in following types: non-modifiable, half-modifiable and fully-modifiable. Fully modifiable laboratories represent highest technological evolution level todays. Using these laboratories user can create not predefined electrical circuits. The laboratories differ in used technologies, components and focus.

Remote laboratories offer all the advantages of the new technology, but they not full replacement for real laboratory work. Using remote laboratories in education students can experience the difference between virtual simulation and real measurement. Next evolution level of remote laboratories should be focused in better replacement of real laboratory. The final goal should be possibility to fully replacement for real laboratory. The goal could be achieved when the students could gain with remote laboratory the same experience as gained by working in real laboratory.

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РАЗВИТИЕ ЛАБОРАТОРИИ ДЛЯ ДИСТАНЦИОННОГО ОБУЧЕНИЯ

Т. Винсе, Р. Балвирчак
Технический университет Кошице
ул. Летна, 9, Кошице, 042 00, Словакия. E-mail: tibor.vince@tuke.sk, rudolf.balvircak@student.tuke.sk

Освещена проблематика отдаленных лабораторий, история их развития и основные шаги эволюции. Последние десятилетия распространение и развитие информационных технологий предоставляет новые возможности также в образовательных и производственных сферах. Одним из новейших преимуществ является возможность осуществления мониторинга и управления работой оборудования с любой точки планеты, возможность дистанционного обучения и др. Сегодня существует много разработок программного обеспечения для моделирования с возможностью моделирования электрических цепей. Однако компьютерное моделирование не является столь же эффективным, как проведение реальных экспериментов. Обучение электромеханике требует в основном практической работы в лаборатории. Удаленные лаборатории позволяют выполнять реальные эксперименты отдаленно и могут предложить все преимущества новейших технологий.

Ключевые слова: дистанционные лаборатории, образование, электрические измерения.

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