Applied Computer Science, vol. 13, no. 1, pp. 85–96
doi: 10.23743/acs-2017-08

Submitted: 2016-12-21
Revised: 2017-01-30
Accepted: 2017-03-15

remote laboratory, iLab , virtual experiment

Tomasz CHMIELEWSKI[*], *Katarzyna ZIELIŃSKA*[**]

SURVEY OF REMOTELY CONTROLLED LABORATORIES FOR RESEARCH AND EDUCATION

Abstract

This paper presents the recent advances in development and utilization of remote laboratories, which can be controlled without physical access to the equipment. Currently observed rapid in-crease of number of such systems is mostly owed to high-speed Internet expansion, as well as the continuous tendency to ensure the open access to modern knowledge. In this paper, various arranges of equipment in such testing rooms are addressed in areas such as electrical engineering, electronics, mechanical engineering. A comprehensive survey of currently most popular remote laboratories worldwide is provided. The paper is concluded by the discussion that presents the authors view point on how remote laboratories may evolve in the future.

1. INTRODUCTION

Nowadays, the computers have dominated almost each and every stage of research and education in technology or medicine. Looking back, however, the experimental work has always been a foundation of science. Therefore, despite the development of powerful virtual instruments (such as simulations) that allow engineers, researchers and students to solve variety of problems, the laboratory work, real-time measurements are still a state-of-the-art standard for introducing any kind of innovation. This can be identified at the research work flowchart presented in Figure 1.

[*] Electrical Engineering and Computer Science Faculty, Lublin University of Technology, Nadbystrzycka 38A, Lublin, Poland, tomasz.chmielewski@pollub.pl
[**] Electrical Engineering and Computer Science Faculty, Lublin University of Technology, Nadbystrzycka 38A, Lublin, Poland, katarzyna.zielinska@pollub.pl

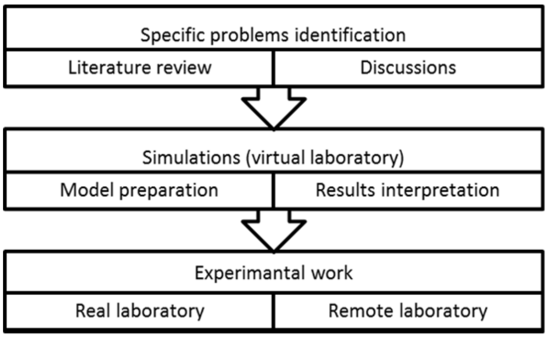

Fig. 1. Experiments in standard research approach

Furthermore, the flowchart in Figure 1 clearly displays a certain classification of carrying out the research or educational experiments. One should notice that there is a clear division on real and virtual environment laboratories with the remote technology being a mix of both (Barrios et al., 2013; Guimaraes, Cardozo, Moraes & Coelho, 2011; Henke, Ostendorff, Wuttke & Vogel, 2012; Nafalski, 2012; Nedic, Machotka & Nafalski, 2003; Orduna, Garcia-Zubia, Irurzun, Lopez-de-Ipina & Rodriguez-Gil, 2011; Tirado, Herrera, Marquez, Mejias & Andujar, 2015). Each way of conducting laboratory work has its pros and cons that may affect the choice of the methodology for a given problem. Nonetheless, it can be noticed that when the experiment is based purely on the computer tools (simulations, virtual lab) one of the research work stages is skipped, which should result in time savings, but also somewhat lower credibility of the outcome. The advantages and disadvantages of each method are listed in Table I.

Tab. 1. Pros and cons of using various types of laboratories for research and education (Nafalski, 2011)

Lab type	Pros	Cons
Real	• Interaction with equipment Work in groups Flexibility • Confirmation of hypothesis	• Cost • Place restrictions • Low accessibility • Supervision required
Remote	• Good for concept explanation • No place restrictions • Medium cost • High accessibility	• Lower flexibility • Indirect interaction with equipment
Virtual	• Good for concept explanation • No place and time restrictions • Low cost • High accessibility	• Idealized data • Results have limited credibility • No interaction with equipment

Due to the increasing complexity, accuracy and consequently cost of today's lab equipment, the standard approach of arranging test rooms has evolved. Constant tendency of cost reduction and simultaneously rising demand of knowledge, especially in modern technology field, calls for alternatives that may meet all of above-mentioned requirements (German-Sallo, Grif & Gligor, 2015; Orduna et al., 2012, 2015; Sivakumar, Robertson, Artimy & Aslam, 2005).

One of the solutions that may address this issue and provide a remedy to the short-comings of experimental work are remote laboratories. In short, the general idea behind the remotely controlled laboratory is to create a hybrid system that utilizes hardware and software. Both of those layers are necessary and equally important in ensuring its proper operation. The software in this case is essentially the interface and the control panel that allows interacting with the hardware. This interaction should be interpreted at few levels that are characteristic to any experiment theses, i.e.: planning, assets assembly and connection, measurements and parameters variation. Software is essential also due to the fact that it guarantees the basic feature of herein discussed concept of experiment which is remote access. Today's remote laboratories are mostly web based, which means that they can be accessed worldwide via internet. The general idea behind the remote laboratory in its modern form is presented in Figure 2. As can be observed, such system operation consists in remote control over physical equipment, such as various measurement equipment, parts, connection routing, experiment parameters and so on.

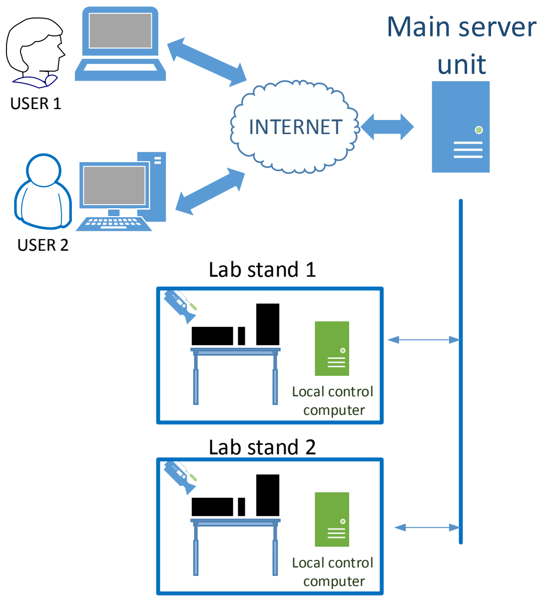

Fig. 2. Experiments in standard research approach

The entire process is supervised via camera picture and virtual interface that should be user friendly and reflect a real laboratory stand in most accurate way. Each laboratory stand needs to be designed in a way that the desired experiment can be assembled automatically. In the case of electrical circuits this means utilization of relays, transistors etc. and when it comes to, for instance, mechanical experiments, there is a need for various motors and actuators that can, for example, move certain elements. Those active parts are typically controlled by the local computer which is then connected to the main server that constitutes a gateway to the external network for all experiments. Thanks to the Internet, users may connect to their experiments regardless of their location. Moreover, the laboratory can be accessed by many users at the same time. A big advantage of such feature is the fact that those users can be only spectators, which is an interesting way of conducting, for instance, a lecture for a very large audience, hence being an excellent educational tool.

2. REMOTE LABORATORIES IN CONTROL ENGINEERING, ELECTRONICS AND PHYSICS

Due to its characteristics the area of automated control and electronics is one of the most suitable for remote laboratories implementation. The features that make those fields suitable for remote laboratories applications are most of all low power, microprocessor based solutions, easy coupling with existing software platforms such as LabView. The examples of such systems are briefly presented and described in this chapter.

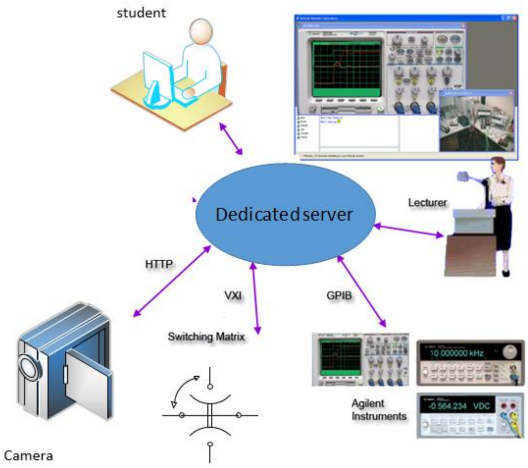

Fig. 3. NetLab architecture (source: http://netlab.unisa.edu.au/index.xhtml)

A good example of the remote laboratory is NetLab (Nafalski, 2011; Nedic et al., 2003), which can be used by academic staff for teaching and demonstrations during lectures, and by students for conducting their experiments remotely on real laboratory equipment (Fig. 3). The lab stand comprises passive, controllable elements, such as resistors, capacitors and inductors. The control is done by relay switching matrix from the graphical GUI prepared in Java. The measurements are taken with digital scopes. The entire experiment can be also observed via a webcam.

In (Gadzhanov, Nafalski & Nedic, 2014) an interesting concept of the laboratory is presented. It serves as a platform for motion control experiments (Fig. 4). It is based on LabView environment LabVIEW Web Services and Remote Front Panels. This not only facilitates the system implementation, but also delivers great numbers of features such as viewer mode. The entire setup comprises a 12 inch linear stage, coupled with a Brushless DC motor and controlled by a high-performance motion controller.

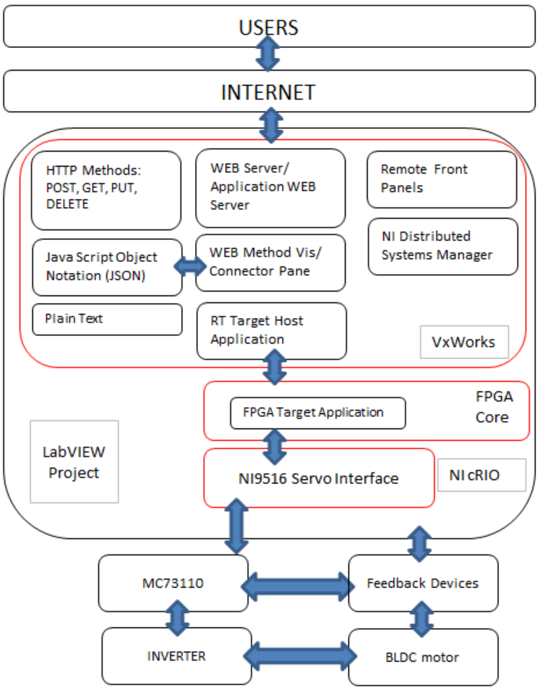

Fig. 4. Architecture of remote laboratory in proposed in (Gadzhanov et al., 2014)

High precision measurements of linear and rotary positions are fed by a resolver and resolver-to-digital converter. The entire setup is governed by the real-time controller with a Field-Programmable GateArray1 (FPGA) core from National Instruments. Such system allow to work with PID controllers and set up desired experiments using user friendly GUI which also displays the measurements. Similar laboratory was described in (Hercog, Gergic, Uran & Jezernik, 2007) where the controlled object is a small DC motor (Fig. 5). The LabView was also used in this case; however, the entire structure of the system is slightly different. It utilizes DSP controllers that are programmed using code generated from Matlab.

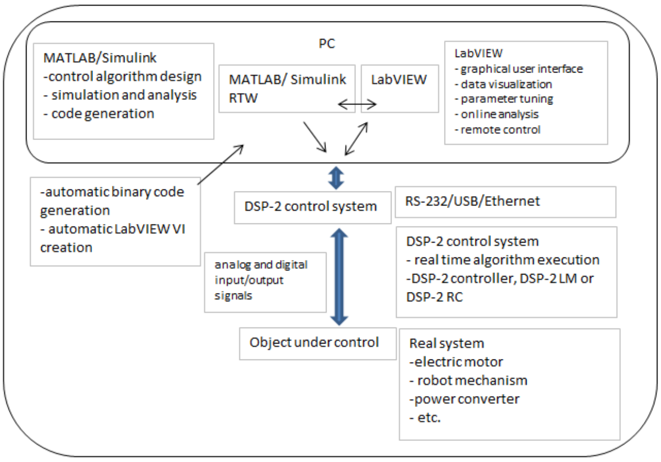

Fig. 5. Architecture of remote laboratory as proposed in (Hercog et al., 2007)

Another example of the remote laboratory which is especially useful for education is described in (Chen & Gao, 2012). PLC controllers are a crucial part of many industry applications and the laboratory described in (Chen & Gao, 2012) allows students to get some more practical knowledge about their operation and programming (Fig. 6). The authors also present a comparative study of learning effectiveness using remote lab which clearly indicates that in this case it could be a solid alternative for a real laboratory.

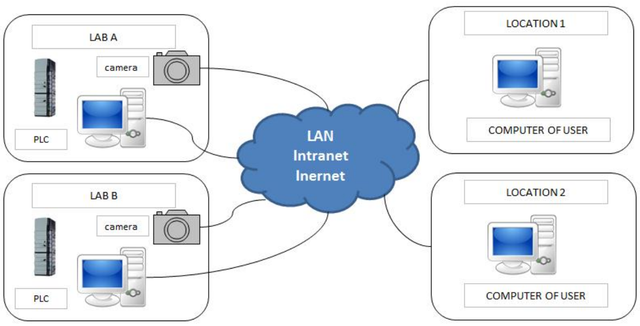

Fig. 6. Architecture of PLC remote laboratory in proposed in (Chen & Gao, 2012)

More examples of how the remote laboratories can be utilized as a tool for control engineering education can be found in (Ayodele, Inyang & Kehinde, 2015; Beghi, Cervato & Rampazzo, 2015; Exel, Gentil, Michau & Rey, 2000; Santana, Ferre, Izaguirre, Aracil & Hernandez, 2013).

Alongside control engineering, there are many other fields that can be experimentally aided by remote laboratories technology. Some of the examples are briefly described in this chapter.

As it is presented in (Del Canto, Prada, Fuertes, Alonso & Dominguez, 2015), certain aspects of cyber security can be also analyzed using the remote laboratory. The authors have proposed a test stand whose main active components are PLC controllers and network scanner. The laboratory uses two virtual machines one of which is responsible for general control over PLC and SCADA signals whereas second one is a vulnerability scanner used for testing safety protocols. The stand is also equipped in a web camera that allows observing the current status of PLC devices.

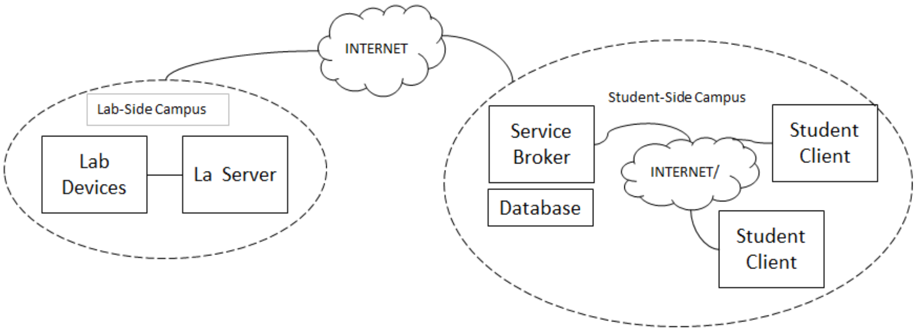

Fig. 7. MIT's iLab architecture (Hardison et al., 2008)

The work from MIT exemplifies how the remote laboratories can be applied even for nuclear (neutron) physics experiments (DeLong et al., 2010; Hardison, DeLong, Bailey & Harward, 2008). The iLab platform (presented in Fig. 7) in this case is used for experiments on the neutron beam that can be generated by the equipment installed therein. The neutron beam is generated by the 5 MW nuclear reactor that may sustain it continuously. Other elements of the lab stand are crystal, detectors, chopper and attenuation materials placed under the support structure (DeLong et al., 2010). Unfortunately, the laboratory has some limitations, namely the neutron beam is not open constantly, but it has to be manually switched on by the lab staff when the experiment is scheduled.

The mechanical systems can be as well experimentally tested in remote laboratories. A very simple test stand for oscillating beam is controlled by LabView installed on the computer. The measurements are performed by two accelerometers. The user may control the beam stimulus with few signals e.g. sinewave, triangle, saw tooth. The user accesses the experiments using LabView due to the fact that the GUI is based on LabView web UI Builder with LabView web services (Cazacu, 2014).

3. ENVIRONMENTAL AND SOCIAL APSECTS OF REMOTE LABORATORIES

The idea of remote and the technology behind it may and already have influenced the society and its view on knowledge and education. The concept of nearly unlimited access to the lab resources may in a future evolve to change of education and research that will affect the daily activities of a students and researchers. Should the remote laboratories were applied on the wider scale, the frequency of students' attendance on traditional classes may be significantly reduced. Considering the fact that students are large group of modern society such change may lead to common benefits. For example decreased number of classes reduces the need for commuting which for some universities whose facilities are spread over large area is at high rate. Reduced number of actively commuting people can be translated to lower traffic which in turn is a direct source of pollution. Another aspect is more efficient use of laboratory space and equipment. The remote laboratory which cannot be physically accessed by the student will not be required to provide the same space as a conventional. It will also apply different health and safety rules. The effect of increased efficiency can be twofold. First is due to the fact that the remote laboratory can be used by more students because of no time restrictions the energy use can be easily managed. This can be especially important for high power tests which could be done in most convenient moment both economically and environmentally. For instance the test can be correlated in time with large energy production from renewables in order not to employ conventional power plants for this purpose.

This extends also on other aspects such as environment. Remote laboratory can classified as a part of internet of things (IoT). IoT is basically a network of interconnected physical objects that are embedded with electronics, sensors and software that are used for data acquisition and exchange. Those devices can be used for variety of purposes this includes also the water, soil and atmosphere quality and pollution, radiation, electromagnetic fields etc. from the environmental point of view. The wide range of applications related to environmental topics is presented in (Estevez & Wu, 2015). Those are related to sensors and their coordination for energy management (e.g. lights control), harvesting the energy from renewables (e.g. PV panels and energy storage monitoring and optimization). The author of (Estevez & Wu, 2015) provides also the application of remote measurements. One of the best example is the air pollution measurement which consequently leads to better monitoring and alerts that when announced lead to pollution reduction e.g. by means of traffic restriction. Based on remote sensors coupled via internet the services can act fast when for instance the weather conditions change and the air pollution rises.

In (Wong, MatJafri, Abdullah & Lim, 2009) authors also propose to apply remote measurements of air pollution by means commonly used internet protocol (IP) camera. The solution utilizes an advances image processing algorithms for determination of PM10 particles concentration in air. Such solution is especially beneficial and cost efficient for highly urbanized areas where the image monitoring (e.g. security, traffic control etc.) is nowadays common. Taking into account the numbers of IP cameras installed in a modern cities the pollution measurement grid could be greatly extended, yielding more data nearly as accurate as the one obtained from the dustmeter. Hence m the research on air pollution could benefit from such measurement system data the research. The access to the measurement and possible image processing algorithm modification is essentially unlimited via the internet. Similar idea was presented in (Wang, Zhang, Huang & Li, 2010) however the "sensors" were in a way aggregated i.e. satellite image was used instead of number of cameras.

One of the finest examples of remote laboratories and how it is indispensable for environmentally related research is presented in (Richter et al., 2016). The authors describe the complex system for research on Bioenergy production from agricultural crop. The system included number of steps such as modeling and observations as well as on site measurements on each considered farm. However, what makes it unique is that the remote control via satellites was performed. Based on the images the farm productivity could be constantly monitored and assessed. Bearing in mind that the research included 23 farms conduction of on-site monitoring would be problematic and time consuming.

In general the remote laboratories and measurements concerning the environmental aspects can be classified as follows:

– Air, water and soil pollution monitoring,
– Whether and lighting contains monitoring for energy management,
– Research on aboveground biomass,
– Remote laboratory for biomass energy heating,
– Research on farming for better biomass production.

Additionally the applications of remote laboratories presented in the preceding sections indirectly affect the environment by decreasing pollution and increasing the energy efficiency. The research and resulting innovations in the area of electronics and control engineering were in fact among the most important factors that reduced e.g. greenhouse gases by the automotive transport. The efficiency of modern petrol and diesel engines is far better than few decades ago.

This is mainly to be owed to the modern electronics that monitors and control the combustions process to make it more efficient. The remote laboratories with the unlimited access for the students and researchers are great stimulant for an innovation also for such applications as energy efficiency and lowering the fuel usage.

4. FUTURE OF REMOTE LABORATORIES

As the technology evolves it provides new, innovative tools that may also affect the way that we think about the remote laboratories. One of the examples of such effect on herein discussed topic are mobile technologies that have recently taken over many areas of our life. Such approach was presented in (Orduna et al., 2011), where the concept of the access via mobile phone was presented. If we could assume that the mobile devices will continue to develop at this pace, then their role as a tool for remote laboratory control will grow. Thanks to that the user could supervise or modify the experiment easily but also receive online notifications about recent parameters of the given process.

Another tool that could revolutionize the remote lab is “virtual reality”. Using devices such as Oculus Rift, one could imagine that the user could actually increase the interaction with the laboratory without physical presence in the test room. This function could be also realized by the holographic 3D imaging.

Robotics could also play a big role in remote lab development. Precise robots could be useful, for example, in chemistry related experiments or in other fields where physical interaction with the equipment is necessary. Remotely-controlled humanoid robots – which could act as a user’s avatar – is not an impossible scenario. Such approach would be especially beneficial for the experiments that have to be performed in clean or hazardous environment.

Last but not least, all the above-mentioned tools could be aided by artificial intelligence (AI). AI protocols could actually help with design of experiment and then, at least in some portion, with the execution e.g. parts or ingredients gathering and delivering to the test stand.

5. SUMMARY

The authors have presented the issue of remote laboratory in research and education with strong focus on showing the wide range of science fields that can make use of this emerging technology. Advantages and disadvantages of remote labs were also compared with simulations and hands-on experiments. The paper discusses also the impact of remote experiments and measurements on environment and prospects for improvement of overall factors that are affecting the environment. Moreover, the authors have speculated on how the remote laboratory topic may evolve in the future.

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