Professional and hobby hands-on-remote experiments

František Lustig, Pavel Brom, and Pavel Kuriščák

View Online

Export Citation

ARTICLES YOU MAY BE INTERESTED IN
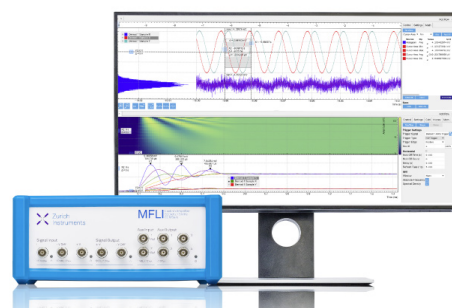
Professional and Hobby Hands-on-Remote Experiments

František Lustig[1, 2, a)] ,Pavel Brom[1, 3, b)], and Pavel Kuriščák[1, c)]

[1]*Charles University, Faculty of Mathematics and Physics, Laboratory of General Physics Education,*
Ke Karlovu 3, 121 16 Prague, Czech Republic
[2]*Jan Evangelista Purkyně university, Faculty of Science, Department of Physics, České mládeže 8,*
400 96 Ústí nad Labem, Czech Republic
[3]*ŠKODA AUTO University, Na Karmeli 1457, 293 01 Mladá Boleslav, Czech Republic*

[a)]Corresponding author: frantisek.lustig@mff.cuni.cz
[b)]pavel.brom@mff.cuni.cz
[c)]pavel.kuriscak@gmail.com

Abstract. This contribution concerns hands-on-remote experiments that were proposed in 2018 by the authors as a new format of school experiments. A hands-on-remote experiment is a traditional hands-on and remotely controlled experiment simultaneously. Professional remote laboratories based on the ISES platform are described briefly. We have finished a new remote experiment on mapping the magnetic field of the Helmholtz coils. Further hobby remote laboratories based on the popular and cheap Arduino platform are discussed. A new fully functional remotely controlled experiment is based on our freely downloadable software kit "Remduino Lab SDK"(available at www.ises.info). With this platform even a non-programmer can build his/her first science remote experiment, featuring the remote control via Internet, live video stream of a real experimental setup and a simple record and download of user's experimental data. Measured values may be simply downloaded to any MS-Excel-like spreadsheet processor. An example of hands-on-remote experiments illustrates their application in physics lessons. The experimental setup can be accessed and controlled remotely from any mobile device like common tablets, notebooks, smartphones, etc. Therefore it can be a traditional hands-on experiment handled locally, and even accessed via near-remote control from students' mobile devices within the class and lesson, which addresses the BYOD (Bring Your Own Device) strategy. After school the experiment remains accessible through far-remote control via Internet. Hands-on-remote experiments can be available for anyone, at any time, and from anywhere and they address both advantages and disadvantages of remote laboratories.

INTRODUCTION

State of art of hands-on, virtual and remote laboratories

Hands-on laboratories are a lifelong part of natural science education. Due to proliferation of computer technologies, some experiments became computer aided (CAE) or computer-based (CBE). In the past, these were distinctly separated from the traditional hands-on counterparts. Nowadays we almost don't acknowledge the separation at all - almost all experiments are computer-assisted in some way without any specific focus on the fact.

Together with the rise of the Internet came virtual laboratories. Relative ease of development in Java, Flash etc. enabled many developers to create new types of experiments. These experiments became interactive, supported with animations, simulations (PhET [1]) or even modelling environments (Easy Java Simulations [2]).

Increased internet bandwidth made remote laboratories possible. At first, they were mostly distributed as specialized client applications, but with advances in web browser technologies they mostly became browser-based.

Remote experiments naturally started appearing with the advent of internet around 1991. First papers on this topic can be found e.g. in [3], [4], [5] and many others. First remote experiments of authors were created around 2002 and they were based on Java runtime environment (JRE) browser plugin [6]. Unfortunately, security issues started reducing

their usability and ultimately rendered JRE obsolete as web technology around 2013. JavaScript took the dominant role of website interactivity and the experiment interfaces had to be completely reworked.

More projects in the overview use various software and hardware platforms (WebLab Deusto from Universidad de Deusto in Spain [7], Remote Experimentation Laboratory RExLAB [8], UNILabs [9] and many others). Most of the remote experiments are based on LabVIEW hardware, e.g. [10], [11], however LabVIEW seems to be too complicated for beginners and non-programmers. Often, remote experiments are based on DIY development platforms with microcontrollers, usually Arduino and Raspberry [12-15].

The number of remote labs worldwide was changing: In 2004 there were approximately 60 remote laboratories, in 2006 the number rose to 120 and in 2011 there were over 300 remote laboratories created – see [16]. In 2016 only 61 remote laboratories were mentioned in [17]. The GO-LAB project [18] offers only 54 remote experiments (19-April-2019). Our project E-laboratory iSES [19] provides 18 online remote labs. It uses our own software solution "iSES Remote Lab SDK" [20] as well as another notable project RemLabNet [21].

New technologies and possibilities started experts' discussions and brought new research questions. This debate has stayed unresolved for decades and ultimately the widely accepted conclusion is that all three approaches have no significant difference in effectiveness for the educational process outcomes (e.g. [22], [23]). American Association of Physics Teachers presented five science lab objectives: 1. experiencing the art of experimentation by students, 2. development of their experimental and analytical skills, 3. support for conceptual learning (mastering of basic physics concepts), 4. understanding the basis of knowledge in physics (based on the inference of experiment and theoretical model outcomes), and 5. development of collaborative learning skills (AAPT [24]). Accreditation Board for Engineering and Technology (ABET) compiled a list of goals and advantages of remote labs: e.g. operation 24/7, possibility of access to costly or dangerous experiments, an introduction of students to the real world of science and technology (with an opportunity to visit more than one laboratory), accessibility to students from developing countries and to other people excluded from laboratory work for various reasons (the rest can be found in [25]). The most frequent conclusions of existing works might result in a recommendation that we should use and combine more strategies considering the fact that various technologies address both common and different learning objectives. Therefore some authors have proposed to integrate all strategies mentioned above, e.g. the integrated e-learning strategy (INTeL) [26].

Our strategy and goals of hands-on, virtual and remote laboratories

What is the progress in the development and dissemination of remote labs? Why is the number of real remote labs so low? We can identify several possible reasons: Remote laboratories are too expensive, they require permanent service and it is hard to create new ones. After 2010 many of the existing remote experiments started to disappear. Universities started to actively block access with passwords and made their remote experiments accessible to their own students only. We feel that too many institutions concentrate on RLMS (Remote Laboratory Management Systems), clouds, Massive Open Online Courses (MOOCs) and Massive Open Online Labs (MOOLs) etc., but no new remote experiments were created recently!

We have been developing remote laboratories for more than 15 years. We have performed numerous demonstrations, workshops, conference presentations, and published many papers. We currently provide 18 freely accessible remote experiments [27]. For the references on the ISES platform see [5], [27, [28], etc.

We launched a free-access website (www.ises.info) that received considerable interest from both teachers and students. Despite the number of web-page hits that our experiments have received, we cannot claim that we were completely successful in bringing more remote experiments into Czech schools. Currently there are approx. 10 big remote laboratory projects in the Czech Republic, that use our "iSES Remote Lab SDK", and around 5 small remote laboratories with one trial experiment. We would like to expand this network to more schools, hands-on-remote experiments might be included in RLMS, clouds, LMS, MOOC and similar resources, instruments, or environments. We have to admit, that number of remote experiments both in the Czech Republic and worldwide is relatively small. Why are educators hesitant to create more remote experiments even though remote labs are 24/7 accessible and enable students to interact with expensive, dangerous or otherwise inaccessible equipment?

The reason might be explained by a relative difficulty of creation of such laboratories. The creator has to be sufficiently qualified not only in physics education, but he also needs sufficient expertise in measurement equipment, computers, Internet, networking, etc. This probably exceeds an average physics teacher's abilities.

Just like some other authors, we observed that it is very important to be physically present near the experiment at first, even though it's remote. If a student sees the experiment physically and subsequently tries to control it remotely

from his smartphone or PC, it completely changes his perception. She/he can no longer "suspect" that the experiment might be a "fake simulation" or a video-on-demand.

In order to bring remote experiments closer to the hands-on ones, we present a new type of school experiment that we call "hands-on-remote" experiment. It can be characterized as a bundle of traditional hands-on and remote experiment, which may be supported by simulations, e-texts and other educational multimedia e-resources as well as other new ICT technology features and RLMS instruments. Moreover, we put focus on user's own experimental data acquisition, simple download and further processing with the use of common PC software like MS Excel. Therefore our approach might help to unite all lab formats mentioned above into one traditional experiment which is the main purpose of this contribution.

Another factor that probably hinders the remote experiment development is a complicated measurement technology, which often requires specialised hardware and software (usually not freely accessible). In the beginning we based our experiments on our own ISES hardware and "iSES Remote Lab SDK" software. Partly because no other solution was available, partly because we wanted to differentiate our approach from other main branches like LabVIEW. Our aim was to use a universal client - web browser, which can run on almost any device in use today. The ISES hardware required a PCI card. Later we developed ISES-USB and ISES-LAN solution, which simplified the connection to a PC. We could have been satisfied with our professional experiments with many web page views and positive feedback, but we really wanted a greater proliferation of remote experiments to other educational institutions.

Therefore, in addition to previous work we tried to build remote experiments based on a very popular and easily accessible Arduino platform. Experiments based on Arduino platform have already been published. The simplest solution has used only Arduino board with a LAN shield. Further experiments have used Arduino and Raspberry boards [12-15]. Our approach, however, uses Arduino Uno board only as an A/D or D/A converter, connected to a PC via USB port. Experiment control and data pre-processing is carried out in our new software kit "Remduino Lab SDK".

This software kit "Remduino Lab SDK" is a result of gradual development. At first, our software kits were relatively complex and specialized. Only very qualified users were able to use them, so for all applications in schools and other institutions, we had to develop the software ourselves. Later we managed to gradually simplify the software so that it could be used as a development kit. Users can simply "glue" together an experiment interface from prepared components like Input, Output, Record, Export or Video Transfer.

PROFESSIONAL REMOTE LABORATORIES

Since 2002 we have been developing a professional platform for remote laboratories with the **system iSES** (ISES-PCI, ISES-USB). There are 18 experiments based on the ISES-PCI board available in our laboratory (see [29]. ISES contains 20 modules and sensors for Physics, Chemistry and Biology remote or local experiments: input modules/sensors (temperature, voltmeter, ammeter, etc.), output modules/sensors (relay, repro, booster, etc.). For more details and technical parameters about ISES modules see [5], [27], [28].

Furthermore, we present here even easier experiment systems called ISES-LAN and ISES-WIN (see the Fig. 1) that include a fully equipped PC. The newest system ISES-LAN and ISES-WIN includes a PC with Windows 10 operating system (not Arduino, Raspberry Pi, etc.). Both feature 2x analog input, 1x analog output channel, 5x digital outputs/inputs with sampling frequency of 100 kHz. Software "iSES Remote Lab SDK" can handle up to 4 ISES-LAN or ISES-WIN units.

The software "iSES Remote Lab SDK" consists of the server and client part. The server-side part of a remote experiment includes experimental hardware connected to a dedicated computer where the MeasureServer application is running (providing two-way communication with the hardware) and optionally the ImageServer application (distributing the video stream captured by the webcam). Clients connect to the experiment via web browsers.

For the creation of user interface of an experiment we have prepared the library of approx. 20 JavaScript components (widgets) called "iSES Remote Lab SDK". This library is freely distributable under Creative Commons license. Individual widgets are highly configurable and provide many thoroughly documented options, which allow even non-programmers to build a complex measurement and control interface with data and video transfer. Among built-in features, users have access to a real-time spline interpolation, simple processing, export of data in various formats, graphical output, and other sophisticated functionality. Widgets use standard web elements, so any web developer can readily modify the default design and fit them to the appropriate page as needed.

FIGURE 1. New measure systems ISES-LAN and ISES-WIN

For non-experienced experiment designers we provide a collection of prepared simple experiments like remote analog record of one quantity (e.g. temperature), remote analog control of one channel (e.g. current booster), remote digital inputs and outputs, time dependence of two or more quantities, XY dependence of input and output quantities, data record, data export, webcam stream etc. The examples have the simplest possible code and mostly use default settings for all components. These simple examples can be arbitrarily merged and combined, so even beginners are able to rapidly develop complex interfaces. They can immediately control their own remote experiments via mobile phones or tablets. Detailed description can be found in [20].

HOBBY REMOTE LABORATORIES

Let's go back to the roots of remote laboratories. New and more complicated technologies of remote laboratories don't take into account that beginners, students, and children at first also want to play with remote devices controlled via Internet and mobile phones. Therefore we have come up with simple Hobby Arduino remote laboratories.

For simple remote experiment we propose to use Arduino-Uno board only as an A/D and D/A converter that is connected via USB port to a PC with the Windows OS (see the Fig. 2).

Lite version of "Remduino Lab SDK" supports the measurement on the input pin A0 (e.g. for temperature sensor) and the control of one digital output pin D3 (e.g. for a relay). Lite version of "Remduino Lab SDK" is freely accessible at our web pages. Visitors will be able to try out and take away the software of the presented experiments for later use. Full version of the kit supports all different Arduino boards with all pins read/write access. Both versions provide input of data, output of data, data record and export function (e.g. to MS Excel).

With the lite version of "Remduino Lab SDK" anyone can try these simple experiments: Capacitor charging and discharging, Volt-Ampere characteristics of LEDs, Temperature control (all freely available at [27] including quick 10-step installation guide). Brief description of the "Remduino Lab SDK" installation follows below.
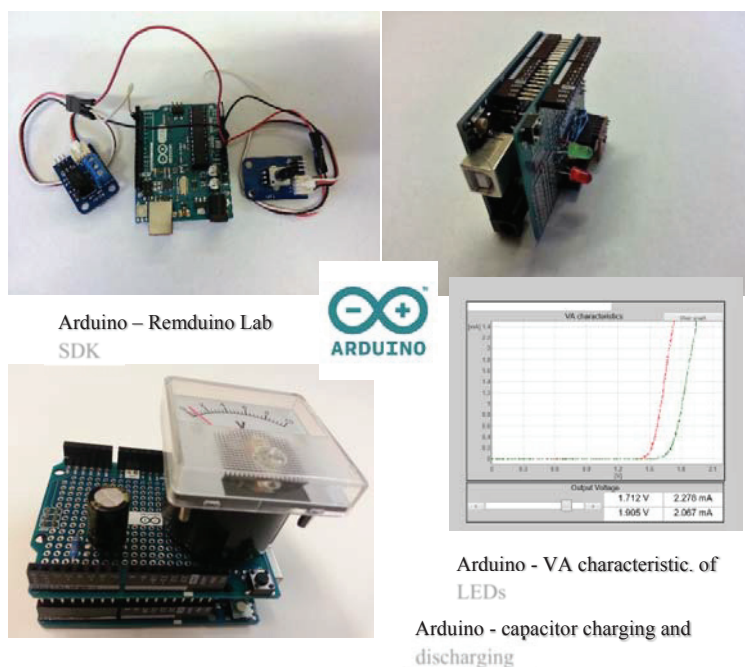
FIGURE 2. Arduino and "Remduino Lab SDK"

"Build your own remote experiment" workshop

Anyone can easily build a remote experiment with cheap Arduino boards, shields and sensors. Interested users may download the files from [27]. "Remduino Lab SDK" zip file containing a complete installation of simple remote experiments, Quick User Guide, and circuit diagrams of all available experiments mentioned above) and follow the instruction in the guide. Tens of non-experienced users managed to finish the whole procedure successfully without our help, and some of them even published their hands-on-remote experiment (public IP address was required).

Another possibility is to take part in our face-to-face "Build your own remote experiment" workshop. No previous knowledge or experience with remote experiments or Arduino are needed. Arduino shields can be borrowed during the workshop, or advanced participants may bring their own Arduino board. Remote control via mobile devices (smartphones, tablets, notebooks) will be possible.

Participants will learn how to troubleshoot common server-client issues. We use three server applications: MeasureServer, WebServer, and optional ImageServer. Participants will learn how to install the software onto the server PC and the Arduino board (using the Arduino IDE environment), how to work with our software development kit "Remduino Lab SDK", how to modify the example control web pages. For the first hands-on-remote experiments of participants our prepared Arduino shields may be borrowed and used. A 15-Euro remote experiment may be finished and published in approx. 15 minutes, our intensive workshop takes around 4 hours, for absolute beginners max. 8 hour workshop is sufficient. For more details the authors may be contacted.

Brief description of the Remduino Lab SDK installation

A new Arduino board can be prepared for hands-on-remote experiments as described in the first five steps of the quick user guide. The following steps can be applied for PCs and Arduino boards. Only the Arduino IDE environment might require running its installer with administrator rights. The software "Remduino Lab SDK" can be downloaded from the main page www.ises.info as a zip file and simply unpacked without administrator rights (e.g. VirtualLab Capacitor Charging and Discharging). Unzipped files may be copied into any destination folder providing the subfolder structure is preserved. Moreover, it is necessary to copy our Remduino library folder into the Arduino library folder. Finally new Arduino PCBs require to upload our "*.ino" configuration file into the board itself via USB cable and the installed Arduino IDE environment.

For PCs and Arduino boards, users need to run our MeasureServerLite application with the selected COM port number specification. Then it is important to run the web server application (here Nginx is used) that can be stopped anytime as needed by the "Stop.bat" batch file situated in the "bin" folder. Running the ImageServer2 application with the "Start Capture" button pressed for live video stream transfer is optional.

The near-remote experiment can be then accessed (running as a server at the same PC) by typing 127.0.0.1, or just *localhost* into the URL address line of any web browser. For the next steps and far-remote control of the experimental setup the IP address of this server PC is needed. The experiment should be accessible from users' mobile devices within the intranet by typing the IP address to the URL address line of any web browser. Only the access via Internet requires a public IP address.

"HANDS-ON-REMOTE" EXPERIMENTS

"Hands-on-remote" experiments are a new approach of experimenting in education. Original school laboratories split up with the advent of PCs and Internet into traditional hands-on labs (including PC aided ones), virtual experiments (simulations), and remotely controlled laboratories. Later their combination back again was proposed within the integrated e-learning strategy (integration of virtual and remote experiments). Here we have proposed a natural integration of all lab formats into one called hands-on-remote experiment.

From observed students' creations of hands-on-remote experiments both in a class (with the teacher's help) or at home we have learned how important the physical presence is for students. Students need to observe a remotely controlled experiment personally. As creators of real remote experiments, we always could see the experimental setup locally, therefore we should let students to experience this for their further motivation. As the teacher presents an experiment in the classroom, students can immediately control it as "near-remote" during the lesson inside the school building. For this purpose it is possible to limit the access to the experiment to a specific group of students or to the school intranet. After school, the students can easily access the experiment as "far-remote" (originally remote), try it out again as a review of the lesson, or in order to download and process their own experimental data to complete a "remote-laboratory homework".

This hands-on-remote experiment approach was tested for the first time at secondary schools involved in the EDUCAnet project in Prague. Since the school has its specialization in information technologies, most of the students had no problems with connection to the experiments. Students were fascinated that such simple hardware like Arduino (with "Remduino Lab SDK") may be controlled remotely with their mobile phones, tablets, etc. Many students were not familiar with the Arduino platform. After finding out how cheap and easily accessible it is, almost all went to buy their own board (PCB) and shields. Subsequently, they were able to run their own simple examples of remote experiments that they had downloaded as a part of the "Remduino Lab SDK" from www.ises.info. Since the software is open-source, the most advanced and active students started to modify it and finalized their own first "hands-on-remote" experiments and shared them with their peers. This is what we regard as the greatest accomplishment: students became remote-experiment creators themselves!

We are aware of the fact that students were most probably interested in the actual remote-control technology rather than in physics. But we believe that once after they become engaged in remote experiments enough, the physics will get their attention as well.

CONCLUSION

The proposed approach addresses both crucial advantages and disadvantages of real hands-on and remote laboratories like the sense of presence, belief in a "remote black box", development of design, experimental and scientific skills, etc. We believe that performing hands-on experiments that are simultaneously remotely controlled is an important aspect of modern experimenting at school.

Arduino platform and the "Remduino Lab SDK" cannot be used for precise or advanced measurements because of limited sampling frequency, ADC-resolution, and safety. But it was designed in order to be used by many beginners.

Since 2002 (before Arduino) we have been developing a professional platform for remote laboratories with the system iSES. On our webpage at http://www.ises.info/index.php/en/laboratory anyone can find a showcase of professional experiments based on "iSES Remote Lab SDK" with the newest laboratory on mapping of the magnetic field of the Helmholtz coils.

We are convinced that students' attitude to remote experiments has been changed positively after students had the opportunity to see (or perhaps to create) the real experiments at school during the lesson. Therefore we expect that our new approach proposed above might give rise to easy remote experimenting with all its advantages.

REFERENCES

1. PhET simulations, [Online], Available:
   https://phet.colorado.edu/en/simulations/category/new, [Accessed: April-19-2019].
2. Easy Java Simulations, [Online], Available: http://fem.um.es/Ejs/, [Accessed: April-19-2019].
3. B. Aktan, et al., IEEE Transact. Edu. **39**, 320-326, (1996).
4. D. Schumacher, Editorial to the special issue, Eur. J. Phys, Vol. **28**, (2007).
5. F. Schauer, et al., Eur. J. Phys, Vol. **29**, 753-765, (2008).
6. ISES WEB Control - software pro vzdalene laboratore se soupravou ISES, 2002-2012, in Czech only, unpublished.
7. WebLab Deusto, [Online], Available:
   https://weblab.deusto.es/weblab/client/?locale=es#page=experiment&exp.category=Visir experiments&exp.name=visir, [Accessed: April-19-2019].
8. Remote Experimentation Laboratory RExLAB, [Online], Available: http://relle.ufsc.br/, [Accessed: 03-Dec-2017].
9. UNILabs, [Online], Available: http://unilabs.dia.uned.es/, [Accessed: 03-Dec-2017].
10. KO, Chung, Chi et al, Education, IEEE Transact. Edu. **44**, 76-86, (2001).
11. P. Bauer, et al., "Survey of distance laboratories in power electronics," in *Power Electronics Specialists Conference*, (PESC 2008, IEEE, 2008), pp. 430-436.
12. M. Kaluz, et al., IFAC P. Vol. **47**, 9057-9062, (2014).
13. J. Sobota, R. Pišl, P. Balda, P. and M. Schlegel, M.. "Raspberry Pi and Arduino boards in control education", in *10th IFAC Symposium Advances in Control Education*, (University of Sheffield, Sheffield, UK, 2013),pp. 7–12, doi: 10.3182/20130828-3-UK-2039.00024.
14. N. Suwondo, D. Sulisworo, iJOE **13**, 116-124, (2017), doi: 10.3991/ijoe.v13i01.6317.
15. V. Cvjetkovic and M. Stankovic, iJOE **13**, 87-105, (2017) doi: 10.3991/ijoe.v13i01.6375.
16. S. Gröber, et al., Eur. J. Phys. **28**. 127-141, (2007).
17. C. A. Matarrita, S. B. Concari, "Remote laboratories used in physics teaching: a state of the art", in *Proceedings of the REV 2016*, 13th International Conference on Remote Engineering and Virtual Instrumentation, (Madrid, Spain. 2016), pp. 376-381.
18. GO-LAB, [Online], Available: http://www.golabz.eu/, [Accessed: April-19-2019].
19. e-laboratory project iSES, [Online], available: http://www.ises.info/index.php/en, [Accessed: April-19-2019].
20. J. Dvorak, P. Kuriscak, F. Lustig, "iSES Remote Lab SDK – internet School Experimental Studio for Remote Laboratory Software Development Kit" , Business and License Agreement: SME RNDr. Frantisek Lustig, U Druhe Baterie 29, 162 00 Praha 6, phone +420 602 858 056, 2013, [Online], [Accessed: April-19-2019], Available: http://www.ises.info/index.php/en/systemises/sdkisesstudio.
21. REMLABNET, [Online], unavailable: http://www.remlabnet.eu, [Accessed: April-19-2019].
22. J. Ma and J.V. Nickerson, ACM Comput. Surv. **38**, article 7, (2006).
23. J. Lang, Teach. & Learn. J. **6**, (2012).
24. AAPT, [Online], Available: http://www.aapt.org/Resources/policy/goaloflabs.cfm, [Accessed: April-19-2019].
25. A. Rosa, "The challenge of instructional laboratories in distance education", ABET Annual Meeting, Baltimore, ABET, 2003.
26. F. Schauer, M. Ozvoldova, F. Lustig, P. Cernansky, "Integrated e-learning - new strategy of the cognition of real world in teaching physics", in *Innovations 2009 (USA)*, World Innovations in Engineering Education and Research iNEER, Special Volume 2009.
27. www.ise.info, [Online], Available: http://www.ises.info, [Accessed: April-19-2019].
28. M. Ozvoldova, F. Schauer, "Remote Laboratories in Research-based education of real world phenomena", Peter Lang. Int. Acad. Publ. Frankfurt, F. Schauer (ed.), 157 p., 2015, ISBN 978-3-631-66394-3.), Villach, Austria.
29. Remote experiments ISES, [Online], Available: http://www.ises.info/index.php/en/laboratory, [Accessed: April-19-2019].