

## “Hands-on-Remote” Laboratories

Frantisek Lustig

Charles University, Faculty of Mathematics and Physics, Prague,  
Czech Republic  
frantisek.lustig@mff.cuni.cz

Pavel Brom

Charles University, Faculty of Mathematics and Physics, Prague,  
Czech Republic  
brpav@seznam.cz

Pavel Kuriscak

Charles University, Faculty of Mathematics and Physics, Prague,  
Czech Republic  
pavel.kuriscak@gmail.com

Jiri Dvorak

Charles University, Faculty of Mathematics and Physics, Prague,  
Czech Republic  
jiridvorak@centrum.cz

**Abstract**—The contribution brings a new solution for remote laboratories. Benefits and effectiveness of hands-on, virtual, and remote labs have been discussed for decades. We have been developing professional and DIY real remote labs for 15 years. Despite our efforts, real remote experiments are unfortunately not so easily feasible as traditional hands-on ones. Experimenting at schools split into three isolated approaches: traditional hands-on labs (including PC-aided experiments), virtual experiments (also simulations, applets), and remote experiments. Recently, some effort to integrate these approaches has appeared (eg. integrated e-learning strategy) although the integration with hands-on experiments is still missing. This state can be explained by high complexity of remote labs and the other limits (budget, availability of HW and SW solution, etc.). Our aim is to show that real remote labs can be easily performed as traditional hands-on labs, and they can be created with both professional equipment and cheap hardware components like Arduino. The goal is an introduction of a new experiment type “hands-on-remote” that is simultaneously hands-on and remotely controlled without need for further modifications. Students themselves may create such experiment or just observe the setup prepared by their teacher, and even operate it remotely by their mobile devices (BYOD). Students may access the experiment from the classroom, school building, and perhaps from their homes after school. Examples of remote labs based both on professional measurement system iSES and Arduino-Uno platform will be presented. Beginners need only an Arduino Uno board with sensors, our freely downloadable “Remduino Lab SDK”.

**Keywords**—hands-on experiment, remote experiment, Arduino, iSES.

# 1 INTRODUCTION

## 1.1 Hands-on virtual and remote laboratories

Hands-on experiments 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. 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. The experiments became interactive, supported with animations, simulations (see PhET [1]) or even modelling environments (Easy Java Simulations (see [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.

New technologies and possibilities started experts' discussions and brought new research questions. This debate has stayed unresolved for decades and it's widely accepted conclusion is that all three approaches have no significant difference in effectiveness for the educational process outcomes (see eg. Ma and Nickerson [3], Lang [4]). American Association of Physics Teachers (AAPT) 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 (see AAPT [5]). Accreditation Board for Engineering and Technology (ABET) compiled a list of goals and advantages of remote labs: eg. operation 24/7/365, 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 for students from developing countries and other people excluded from laboratory work for various reasons, (for others see [6]). The most frequent conclusions of existing works may 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, eg. the integrated e-learning strategy (INTeL, see [7]).

## 1.2 Hardware and software solution for real remote labs

Remote experiments naturally started appearing with the advent of internet around 1991. First papers on this topic can be found e.g. in [8], [9], [10] and many others. First remote experiments of authors were created around 2001–2002 and they were based on Java runtime browser plugin [11]. 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.

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 [12]. In 2016 only 61 remote laboratories were mentioned in [13]. The GO-LAB project [14] offers only 63 remote experiments (25-November-2017). Our project E-laboratory iSES [15] provides 18 online remote labs. It uses our own software solution “iSES Remote Lab SDK” [16] as well as another notable project RemLabNet [17].

More projects in the overview use various software and hardware platforms (see WebLab Deusto from Universidad de Deusto in Spain [18], Remote Experimentation Laboratory RExLAB [19], UNILabs [20] and many others). Most of the remote experiments are based on LabVIEW hardware, e.g. [21], [22], however LabVIEW seems to be too complicated for beginners and non-programmers (see section 3.4). Often, remote experiments are based on DIY development platforms with microcontrollers, usually Arduino and Raspberry [28], [29], [30]. Recently we have seen some remote experiments based on FPGA development platform [32].

What is the progress in the development and dissemination of remote labs? Why the number of real remote labs is 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 [23], Massive Open Online Courses (MOOCs) and Massive Open Online Labs (MOOLs) [24] etc., but no new remote experiments were created recently!

## **2 GOALS, MOTIVATIONS FOR A CHANGE**

We have been developing remote laboratories for more than 15 years. We have performed numerous demonstrations, workshops, conference presentations, and published many papers. We launched a free-access website ([www.ises.info](http://www.ises.info)) that received considerable interest from both teachers and students. Despite the number of web-page hits our experiments have received, we cannot say that we were completely successful in bringing more remote experiments into Czech schools. Currently there are approx. 10 bigger remote laboratory projects in Czech Republic, that use our “iSES Remote Lab SDK”, and around 10 small remote laboratories with one trial experiment. We would like to expand this network to more schools to make full use of RLMS, cloud, MOOC and other technologies. We have to admit, that number of remote experiments both in 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 experiments. The creator has to be sufficiently qualified not only in physics education, but he also has to have sufficient expertise in measurement equipment, computers, internet, networking etc. This probably exceeds an average physics teacher's abilities.

We consider ourselves to be pioneers in the remote experiment field (our first remote experiment went online in 2002 and is still available - see "Water level control", (<http://kdt-34.karlov.mff.cuni.cz/en/mereni.html>)). 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. This new approach to remote experimenting is a main point of our 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 today. The ISES hardware required a PCI card. Later we developed ISES-USB 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.

At first we developed the support for standard measuring equipment like COM/USB enabled multimeters and other measuring devices. Immediately after that 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 [25]-[29]. Our approach uses Arduino Uno board only as an A/D or D/A converter, connected to a PC via USB port. The control and data pre-processing is carried out in our new software kit "Remduino Lab SDK".

This software kit is the result of a 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 appropriate 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. This software kit still supports the whole hardware ranging from ISES systems, COM/USB devices to Arduino boards.

### 3 “HANDS-ON-REMOTE” EXPERIMENT

#### 3.1 “Hands-on-remote” experiment with iSES systems

**Hardware:**

Modular system iSES (internet School Experimental Studio) communicates with different measurement platforms. 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..



**Fig. 1.** New measure systems ISES-LAN and ISES-WIN

ISES has 20 modules and sensors for Physics, Chemistry and Biology for remote or local experiments: input modules/sensors (temperature, voltmeter, ammeter...), output modules/sensors (relay, repro, booster, etc.). For more details and technical parameters about ISES modules see [www.ises.info](http://www.ises.info).

**Software:**

Server-side part of a remote experiment consists of experimental hardware connected to a dedicated computer that runs the MeasureServer and optionally the ImageServer application. The MeasureServer provides two-way communication with the hardware, while ImageServer distributes the video stream captured by the webcam. Since the real-time data transfer is realized using the WebSocket technology, a web server has to be also installed and running. In the most of our experimental setups, the web server runs on the same dedicated computer and provides both user interface in a form of a webpage and relays the WebSocket connection to the MeasureServer. Clients connect to the experiment using regular web browsers.

To create a user interface of an experiment we have prepared the library of approx. 20 JavaScript components (widgets) - “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.

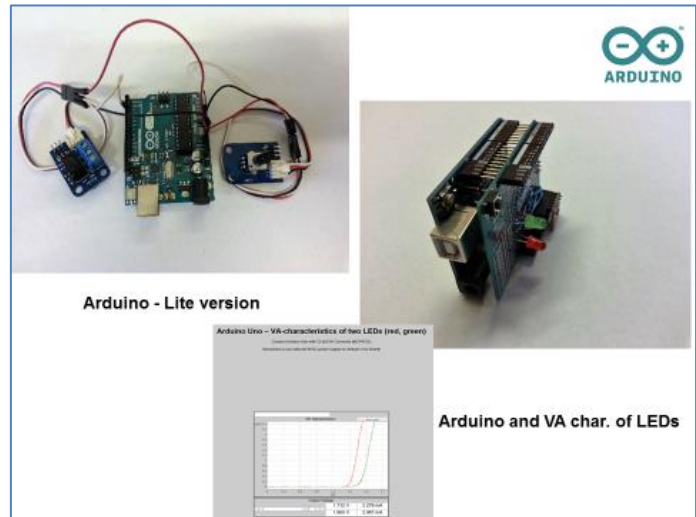
**“Hands-on-remote” easy experiments with iSES:**

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. This set of examples can be accessed online on <http://www.ises.info/index.php/en/systemises/collection>. Detailed description can be found in [30], [31].

**3.2 “Hands-on-remote” experiment with Arduino platform**

**Hardware:**

For simple “hands-on 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 Figure 2).



**Fig. 2.** Arduino and “Remduino Lab SDK”

### ***Software:***

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 relay). Full version of the kit supports all different arduino boards with all pins read/write access. Both versions provide data record and export function (e.g. to MS Excel), and the full set of functions of the “iSES Remote Lab SDK”.

### ***“Hands-on-remote” easy experiments with Arduino:***

Examples from the freeware “Remduino Lab SDK - lite version” will be presented on example projects like the volt-ampere characteristics of LEDs, capacitor charging and discharging, mass-on-spring oscillations or a simple automatization project “heating and cooling”.

## **3.3 “Hands-on-remote” experiments with students in classroom**

“Hands-on-remote” experiments with iSES were presented at several Czech conferences in 2017. Participants were surprised how quickly one can build a remote experiment that is simultaneously traditional hands-on and remote. At the REV2018 conference we want to present this approach as well. Since September 2017 the platform has been tested at two secondary schools in the Czech Republic.

One of them is a school from the EDUCAnet network. Schools within this network have a common specialization and heavily utilize mutual network connection. EDUCAnet received a generous European grant to build a pilot remote laboratory with hands-on-remote experiments. These experiments would be shared with other schools in EDUCAnet network. The project will be realised in 2018.

Before the grant application, the school performed a pilot testing. We would like to present short video excerpts from these lessons. 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.

Through this experience we understood how important the physical presence is for students. They need to observe a remotely controlled experiment personally at first. As creators of such experiments, we always could see the experiments locally, therefore let students to experience this as well for their further motivation.

As the teacher presents an experiment in the classroom, students can immediately operate it as “near-remote” during the lesson from 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”, try it out again as a review of the lesson, or download and process their own experimental data to complete a “remote-experiment homework”.

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 they become engaged in remote experiments enough, the physics will get their attention as well.

Many students were not familiar with the Arduino platform. After finding out how cheap and easily accessible it is, almost everyone went to buy his own board. Subsequently, they were able to run their own simple examples of remote experiments that they downloaded as a part of the “Remduino Lab SDK” from [www.ises.info](http://www.ises.info). Since the software is open-source, the most advanced and active students started to modify it, finalize their own first hands-on-remote experiments and share them with their peers. This is what we regard as the greatest accomplishment - students became remote-experiment creators themselves!

During 2018 we can expect more interesting results after the completion of the European grant.

### **3.4 Comparison to alternatives**

Our “Hands-on-remote” laboratories might resemble e.g. a LabVIEW Remote Front Panel that enables to simply turn a local experiment into a remote one. LabVIEW Remote Front Panel, however, requires full installation of the LabVIEW Run-time Engine (large installation files, limited rights for installations in students’ labs, lack of support by the majority of web browsers or mobile devices like smartphones) [33]. Moreover, LabVIEW is a commercial paid product, therefore it’s less suitable to beginners and non-programmers.

Our new “hands-on-remote” experiments do not require any additional installations, remote experiment can be published and shared in approx. 10 minutes. Hands-on-remote experiments are accessible via smartphones and other mobile devices

## **4 CONCLUSIONS**

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> you can find a showcase of professional experiments based on “iSES Remote Lab SDK”.

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.



We believe that remote experiments with Arduino and the “Remduino Lab SDK” might become the dreamed Massive Open Online Labs (MOOLs), which are used by many participants and featuring a greater number of real remote experiments.

## 5 Acknowledgment

The work was supported by The Small and Medium Enterprise ISES, RNDr. Frantisek Lustig, Prague, Czech Republic.

## 6 References

1. PhET simulations. [Online]. Available: <https://phet.colorado.edu/en/simulations/category/new>. [Accessed: 03-Dec- 2017].
2. Easy Java Simulations [Online]. Available: <http://fem.um.es/Ejs/>. [Accessed: 03-Dec-2017].
3. Ma, J. and Nickerson, J.V. Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review. *ACM Computing Surveys*, vol. 38, no. 3, 2006.
4. Lang, J. Comparative Study of Hands-on and Remote Physics Labs for First Year University Level Physics students. *Teaching & Learning Journal*. Volume 6. Issue 1. 2012
5. AAPT. [Online]. Available: <http://www.aapt.org/Resources/policy/goaloflabs.cfm> [Accessed: 03-Dec- 2017].
6. Rosa, A. The challenge of instructional laboratories in distance education, ABET Annual Meeting, Baltimore, ABET, 2003.
7. Schauer, F. Ozvoldova, M. Lustig, F. Cernansky, P. Integrated e-learning - new strategy of the cognition of real world in teaching physics, *Innovations 2009 (USA)*, World Innovations in Engineering Education and Research iNEER. Special Volume 2009.
8. Aktan, B. Bohus, C. Crowl, L. and Shor, M. H. Distance Learning Applied to Control Engineering Laboratories. *IEEE Transactions on Education*. Vol. 39. No. 3. August 1996. pp. 320-326.
9. Schumacher, D. Student Undergraduate Laboratory and Project Work. Editorial to the special issue. *Eur. J. Phys.* Vol. 28. No. 5. 2007.
10. Schauer, F. Lustig, F. Dvorak, J. Ozvoldova, M. An easy-to-build remote laboratory with Data Transfer Using the Internet School Experimental System. *Eur. J. Phys.* Vol. 29. 2008. pp. 753-765.
11. ISES WEB Control - software pro vzdalene laboratore se soupravou ISES, 2002-2012, in Czech only, unpublished. [Online] [http://www.ises.info/old-site/index.php?f=relizace\\_vzdexp](http://www.ises.info/old-site/index.php?f=relizace_vzdexp), [Accessed: 03-Dec- 2017].
12. Gröber, S. Vetter, M. Eckert, B. and Jodl, H.-J. Experimenting from a Distance-Remotely Controlled Laboratory (RCL). *Eur. J. Phys.* Vol. 28. pp. 127-141. 2007.
13. Matarrita, C. A. Concari, S. B. 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.
14. GO-LAB, [Online]. Available: <http://www.golabz.eu/>, [Accessed: 03-Dec- 2017].
15. e-laboratory project iSES, [Online]. Available: <http://www.ises.info/index.php/en> [Accessed: 03-Dec- 2017].  
Dvorak, J. Kuriscek, P. Lustig, F. 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: 03-Dec-2017], unpublished.  
Available: <http://www.ises.info/index.php/en/systemises/sdkisesstudio>,
16. REMLABNET, [Online]. Available: <http://www.remlabnet.eu>, [Accessed: 03- Dec-2017].
  17. WebLab Deusto, [Online]. Available:  
<https://weblab.deusto.es/weblab/client/?locale=es#page=experiment&exp.category=Visir experiments&exp.name=visir>, [Accessed: 03-Dec-2017].
  18. Remote Experimentation Laboratory RExLAB, [Online]. Available: <http://relle.ufsc.br/>, [Accessed: 03-Dec- 2017].
  19. UNILabs, Available: <http://unilabs.dia.uned.es/>, [Accessed: 03-Dec-2017].
  20. KO, Chung, Chi et al. Development of a web-based laboratory for control experiments on a coupled tank apparatus. *Education, IEEE Transactions on Education*. 2001, 44.1: 76-86.
  21. Bauer, P. et al. Survey of distance laboratories in power electronics. In: *Power Electronics Specialists Conference*. 2008. PESC 2008. IEEE. 2008. p. 430-436.
  22. Schauer, F. Krbecek, M. Beno, P. Gerza, M. at al REMLABNET - open remote laboratory management system for e-experiments. In *Proceedings of the REV 2014*. Porto. Portugal. ISBN 978-1-4799-2025-9.
  23. Salzmann, Ch. Pignet, Y. Gillet, D. MOOLs for MOOCs, a first edX scalable implementation. In *Proceedings of the REV 2016*. 13th International Conference on Remote Engineering and Virtual Instrumentation, Madrid. Spain. 2016. pp. 240-245. ISBN: 978-1-4673-8245-8.
  24. Kaluz, M. Cirka, L. Valo, R. Fikar, M. ArPi Lab: A Low-cost Remote Laboratory for Control Education, In *IFAC Proceedings Volumes, Volume 47, Issue 3, 2014, Pages 9057-9062*, ISSN 1474-6670, ISBN 9783902823625, <https://doi.org/10.3182/20140824-6-ZA-1003.00963>. (<http://www.sciencedirect.com/science/article/pii/S1474667016430430>)
  25. Sobota, J., Pišl, R., Balda, P., and Schlegel, M. (2013). Raspberry Pi and Arduino boards in control education. In *10th IFAC Symposium Advances in Control Education*, 7–12. University of Sheffield, Sheffield, UK. doi: 10.3182/20130828-3-UK-2039.00024.
  26. García-Zubia, J., Angulo, I., Hernández, U., and Orduña, P. (2008). Plug&play remote lab for microcontrollers:WebLab-Deusto-pic. In *7th European Workshop on Microelectronics Education*, 28–30. Budapest, Hungary.
  27. Suwondo, N. Sulisworo, D. Hands-on Learning Activity Using an Apparatus for Transient Phenomena in RC Circuit Based on Arduino UNO R3-LINX-Labview. *iJOE*. Vol 13. No 01 (2017). pp. 116-124. <https://doi.org/10.3991/ijoe.v13i01.6317>
  28. Cvjetkovic, V. M. Stankovic, U. Arduino Based Physics and Engineering Remote Laboratory. *iJOE*. Vol 13. No 01 (2017). pp. 87-105. <https://doi.org/10.3991/ijoe.v13i01.6375>.
  29. Krbecek, M. Schauer, F. Lustig, F. EASY REMOTE ISES – Environment for Remote Experiments Programming. *Innovations 2013: World Innovations in Engineering Education and Research*. W. Aung, et al. (ed.). iNEER. Potomac. MD. USA. pp. 80 – 101.
  30. Ozvoldova M. Schauer, F. 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.
  31. Toyoda, Y. Koike N. and Li Y. An FPGA-based remote laboratory: Implementing semi-automatic experiments in the hybrid cloud," 2016, in: *13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*, Madrid, 2016, pp. 24-29, doi: 10.1109/REV2016.7444435.
  32. NI, [Online]. [Last Update: 31-Mar-2017] [Accessed: 01-Dec-2017]. Available: <http://digital.ni.com/public.nsf/allkb/151BE12C055F57CE86257043006CB4B3>