



# **Tomas Bata University in Zlín**

## **Faculty of Applied Informatics**

Doctoral Thesis Summary

### **Tvorba a správa výzkumných vzdálených laboratoří na úrovni EU**

**Creation and administration of research remote laboratories at EU level**

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*Key words: Remote laboratory, remote experiment, remote laboratory management system, RLMS, security, remote laboratories development environment, laboratory federalisation, LTI, RLMS federalisation, REMLABNET.*

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## **ABSTRAKT**

Současná společnost se vyznačuje sdílením zdrojů a aktiv prostřednictvím Internetu a rostoucí virtualizací v oblasti informačních a komunikačních technologií (IKT). Tento přístup šetří náklady za drahá zařízení, které jsou sdílena a dostupná prostřednictvím sítě. Podobný trend lze nalézt v širokém spektru oblastí lidské činnosti obecně a zejména ve vědě a učebních procesech. Nedávný vznik vhodných informačních a komunikačních technologií umožňuje sledování a řízení fyzického laboratorního vybavení prostřednictvím Internetu a umožňuje tak vývoj online vzdálených laboratoří. Je důležité si uvědomit, že vzdálené laboratoře jsou laboratoře, které jsou přístupné a říditelné online. Liší se od svých virtuálních protějšků, neboť se jedná o skutečná fyzická zařízení nikoliv simulace.

Takové laboratoře jsou vytvářeny po celém světě. Neexistuje však jednotná specifikace ani přístup k jejich konstrukci. Proto existuje tendence sloučit tyto laboratoře do velkých sítí a vyrovnat jejich rozdíly včetně sjednocení jejich komunikačního rozhraní. Tyto sítě jsou spravovány systémy řízení vzdálených laboratoří. Tato doktorská práce je zaměřena na návrh a tvorbu komplexního softwarového řešení pro vzdálené laboratoře. Toto řešení by přitom mělo zabezpečovat nejen správu, ale také tvorbu a provoz vzdálených laboratoří.

## **ABSTRACT**

The contemporary society is characterized by sharing of resources and assets through the Internet and growing virtualization in Information and Communication Technology (ICT). This approach saves the cost of expensive shared devices, available through the network. This trend can be found in a wide range of sectors of human activities in general and in science and teaching processes in particular. The recent emergence of appropriate ICT enables physical laboratory equipment to be monitored and manipulated through the Internet and has therefore facilitated the development of online or remote laboratories. It is important to note that remote laboratories are those that can be accessed and manipulated online; they differ from their virtual counterparts as they deal with real physical equipment rather than simulations.

Though such laboratories are being created all over the world; however, there is no unified specification or approach to their construction. Therefore, there is a trend to merge these laboratories into large grids and offset their differences with unification of their communication interface. These grids are operated by remote laboratories management systems. The thesis is focused on the design and creation of a complex software solution for the remote laboratories. Such complex solution should cover not only the administration but the creation and flawless operating of remote laboratories as well.

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# 1. INTRODUCTION

The contemporary society is characterized by sharing of resources and assets through the Internet and growing virtualization in ICT. This approach saves the cost of expensive devices, now available through the network. This trend can be found in a wide range of sectors of human activities in general and in science and teaching processes in particular. The recent emergence of corresponding Information and Communication Technology (ICT) enables physical laboratory equipment to be monitored and manipulated through the internet, and has therefore facilitated the development of online or remote laboratories [1], [2].

## 1.1 Remote laboratories

The RL is actually a real experiment running in a real laboratory by using real instruments and equipment. It can be controlled by researcher, teacher, student or any other user from his/her computer through the Internet on the general server-client [3]-[6] controlling scheme. Controlling of the laboratory is enabled via Web interface, by means of which the user can perform the appropriate settings, options, and starting or stopping the experiment. The measured data from the laboratory are transferred across the Internet and presented through the web interface to the client. Most of the laboratories include the Web camera that allows monitoring the on-going experiment in real time and/or communication with the tutor [7]. With the necessary exceptions (maintenance, modification, technical issues...) experiments are running on 24/7 scheme [8]-[10].

Creation of the remote laboratories is mainly matter of universities or scientific organizations at this moment. It is not for financial reasons but rather for difficulty of their creation. A person, who is not familiar with Information Technologies (IT) and basics of some programming language, is not able to create full-fledged remote laboratory. This is a reason why the spread of RLs is not as fast as it could be. Besides scientific field another main field of RLs usage is a teaching process. Unfortunately, there are plenty of tutors who encountered above mentioned problems.

There are rather standalone RLs than big RLs across the Europe. Most of these RLs were created as a part of some funding projects. Unfortunately, this approach very often leads to the end of RL after the project completion. There is a lack of maintenance and competent staff to do it. Because of that, there are only a few RLs with continuous run and proper support.

## **1.2 Remote Laboratory management systems (RLMSs)**

The contemporary trend suggests that in the future most of RLs will be merged into large systems - Remote Laboratory management systems (RLMS). RLMS is an emerging and recently elaborated trend that receives increasing attention among many universities in USA [11] and Australia [12]. This approach highlights new basic research aspects of integrating diverse remote lab systems. This integration is associated with many challenges which have to be managed by each university willing to wrap a pool of existing remote laboratories in a RLMS. There has been two large RLMS pioneering in this field, which are described below same as the list of major European successors.

### **1.2.1 iLab Shared Architecture**

First RLMS is called iLab [11]. Jesus del Alamo started the iLab Project in 1998 although it was several years before the project acquired its final name. The initial inspiration for the first iLab came from the frustration that MIT's courses on semiconductor devices did not contain a laboratory component [13]. Since that time the system was developing until today. Despite the efforts to include more world laboratories, iLab is currently used primarily for the purposes of MIT and several other American and Australian universities. As a limitation of European extensions of this system may be the need to use exact approach in the process of lab creation. Installation of the software at the client side may by also consider as a disadvantages of this system. On the other hand iLab brings many principles and standards which was globally adopted and used for next development of the RLs field.

### **1.2.2 Sahara**

Second system is called Sahara [12]. This RLMS was developed within national Australian project formed in late 2008. The project had funding of \$3.8 million over 3 years. It's a nationally shared network of remote laboratories in the context of Australian higher education institutions. Currently there are over 50 rigs in Sahara. System also provides many features like a booking system, collaboration, video and audio interaction and more [14]. Sahara is a part of The Labshare Institute (TLI). TLI operates as a service provider for peer-to-peer networks of shared remote laboratory infrastructure. Services will be rendered through a subscription basis. Because of the subscription fee, the usage of this system is limited. There are several Australian universities which paid for the



joining to this institute. However this paid model was refused by an overwhelming majority of the European universities.

### **1.2.3 European RLMSs**

At the start of the presented PhD research there was not any RLMS which could be globally used or adopted across the Europe. However, during past years several projects arose aiming to creation of such a system. Most of them did not reach appropriate size and level to be used globally. One of the exceptions is the system called WebLab-Deusto.

**WebLab-Deusto** is an open source RLMS developed by the University of Deusto since October of 2004. The WebLab-Deusto team, led by Javier Gacia-Zubia, had been involved in educational remote experimentation since 2001. The first version was developed by two industrial electronics engineering students. It was focused on the hardware part of the RL, attending to the peripherals and the automation of the required tasks [15]. The current version of the system is fully developed RLMS with many functions.

There are other systems [16]-[19] which, while may not be a remote laboratory management system or have the impact of the ones mentioned above, are worth being noted in before continuing.

## **1.3 Federalisation**

During presented PhD research the trend of RLMSs changed. The idea of integration into one over embracing RLMS which could serves for most RLs across the Europe was abandoned. The reason of this change came from the diversity of individual RLs and the approaches of their owners. Most of emerged RLMSs are more or less focused on the specific HW of their RLs'. They allow inclusion of another HW types but in most cases it means limitation of provided features. This circumstances created insurmountable barrier and halted any integration efforts.

Another barrier was in the approach of RL administrators. Some of them are happy to include their RLs into big RLMSs but the other group would rather prefer to adopt some open source solution and manage it by themselves. There was also a group of those, who were not inclined to be included with their RLs in any foreign RLMS, and wanted to create their own only for their RLs. On the other hand, even if the approaches of administrators varied, they usually share the common goal of the progress and sharing of RLs to the world.

For all these reasons the trend was shifted from one big RLMS to the creation of network with many specialized RLMSs sharing their RLs and resources with each other. This trend is called **federalisation** of RLMSs. Let us describe the functionality of RLM federalisation in in more detail.

The remote laboratories can be easily shared with other institutions. This sharing can be managed in a simple way: the provider institution (the one where the equipment is located) creates accounts for users of the consumer institution (the one interested in using the provider equipment). Users of the consumer institution directly access the provider institution system and the provider institution does all the work in the terms of authentication, authorization and providing access to the laboratory [15].

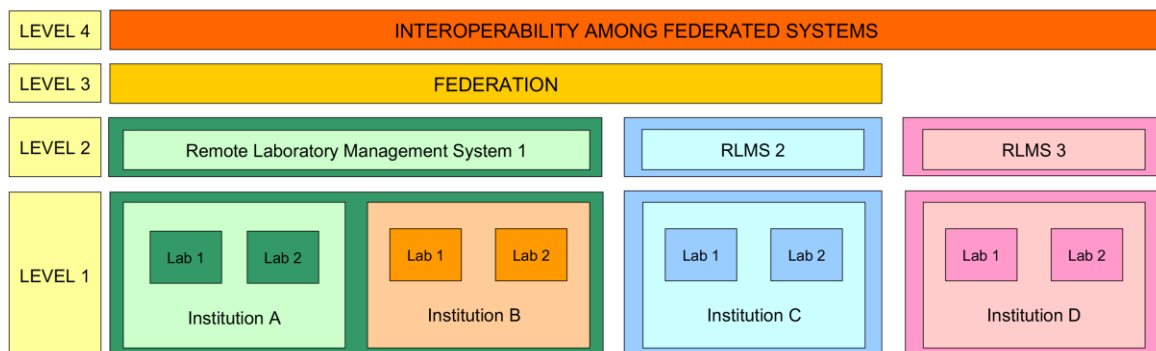
Unfortunately, this solution bears multiple problems. First, the provider institution must create and manage the users' accounts of all the interested consumer institutions. In a complex scenario, where a wide variety of consumers are involved - such as foreign universities and even high/secondary schools that do not master the provider's language, this approach does not fit. Second, the management of this approach is cumbersome: consumer institutions would need to notify providers every change at users' accounts. Third, the consumer institution cannot carry a proper accounting of the uses performed: it must trust the provider institution. If both institutions come to an agreement where users of the consumer institution can access up to 10,000 times, there will be no way for the consumer institution to audit this.

In order to handle these and other problems, a two-side model is required, where both institutions have the same software framework that manages this sharing. The consumer institution can authenticate and authorize local students, and once authorized, the local framework will contact the provider institution and request an access. This way, the provider institution does not need to manage users of the consumer institution, and the consumer institution can track all the requests performed to the provider institution, being able to track users and audit the overall use.

Taking into account all above mentioned concepts the four different levels of federation could be formulated (Figure 1).

- **Level 1:** This level contains RL itself which are created to allowing distance measurement or observation of particular phenomena.

- **Level 2:** Next level includes RLMSs which manage RLs of one or more involved institutions. They provide standard functions like authentication, authorisation and providing access to RLs from level one. They may also provide other features like RL scheduling, statistics and administration tools or tools enhancing measurement process and user experience.
- **Level 3:** Federation of RLs take place at this level. This federation is based on sharing of RLs from one institution to another. It is usually designed as one special function of RLMSs from level two taking care of federalisations. RLMS adopted one of the federation models and managed the RLs sharing according to model's principles.
- **Level 4:** This level of federalisation forms the top of the hill with respect to Interoperability among federated systems. As was mentioned there are differences between particular federation models. This level allowing interoperability between these models unifying their communication interface to this level and opens the possibilities of sharing RLs despite their differences.



*Figure 1 Scheme of federalisation levels*

The requirements between particular parts of this scheme are passed from bottom to up. Remote laboratories require certain features that are implemented by the RLMSs. The RLMSs support different generic ways to manage these labs, such as common scheduling schemes or life cycles. These schemes and interfaces are pushed up so the federation models are defined on top of them. Finally, interoperability layers at federation level will have to deal with the requirements of the different types of federation models

## 2. GOALS OF THE PhD THESIS

The goals of the thesis are focused on the design and creation of a complex software solution for the remote laboratories. Created system should cover creation, administration and operating of remote laboratories and serve for the international usage. This task was divided into followings goals:

1. **Bringing RLs to layman in the field** - Spreading of the remote laboratories is at present limited by the knowledge demands for their creation. To solve this problem the new procedure for the creation of remote laboratories will be designed.
2. **Creating of remote laboratories development environment** - For substantial simplification of the remote laboratory creation process the new development environment will be designed and created with utilisation of the newly proposed procedures for the creation of remote laboratories.
3. **Enabling RLs to mobile devices** - According to the new trends remote laboratories have to be designed and optimised for the technology of mobile devices. All these optimisations will be automated in created development environment.
4. **Setting up the diagnostic server for the remote experiments** - Remote laboratories have to be operable in 24/7 mode. This reliability must be secured by advanced diagnostics. The new diagnostic principles will be proposed and used for creation of robust diagnostic server as a part of RLs.
5. **Designing the remote laboratories management system** - Remote laboratories are mostly created as stand-alone units with limited or none possibilities for the advancement, administration or sharing of the laboratories on a larger scale. The new open remote laboratory management system will be designed and created providing functions for the management, sharing and features enrichment of remote laboratories at international level.

### **3. USED METHODS AND PRINCIPLES**

This thesis is mostly focused on the development of the new software solutions the used methods and principles corresponding with this focus. This chapter describes the general methods and principles used during the software design and development, but also those exclusively designed and aimed at this research. These are divided into three parts according to the particular tasks of the thesis describes the principles, methods and corresponding schemes and structures of designed solutions for these tasks. The principles and schemes described in this part are the results of undertaken research which led to the proper design and the development of the complex remote laboratories system according to the research goals of the thesis.

#### **3.1 Security of Remote laboratories and their management systems**

Only recently has emerged a serious problem resulting from security aspects of RLs. As the chain is always as strong as its weakest link, it is necessary to start from the security of basic constituent of the system which is RL. Therefore the description of the security precautions of RL itself based on the security analysis is presented as first.

##### **3.1.1 Design of specific security precaution for RLs**

RLs can be divided into three categories according to their sophistication (basic, complex, scientific) [20]. The level of security will vary depending on the type of laboratory sophistication. Proposed precautions are based on the security analysis carried out during this research. Designed security methods were adopted as guidelines for security in proposed RLMS (Chapter 4.4).

##### **3.1.2 Security in RLMS design**

Since the designed RLMS could be in general considered as an information system, its security specification comes from basic standards [21] of these systems. RLMS is operated at the virtualized servers in datacentre; therefore, the online security of the system is addressed at this level and is not dealt with in this thesis.

However, the security of RLMS is also determined by the security of RLs which was described above. All RLs currently involved in RLMS and placed at FAI UTB (under our management) are treated according to the proposed

security principles. Their security is universally solved at the level of complex RLs. In addition to the conventional security, such as antivirus and firewall, several other measures was implemented that may help in their protection. One of them is users' actions logging which does not guarantee safety itself, but allows the detection and analysis of failures or malfunctions. According to adopted principles RLs provide security through user's registration and authentication. All of them were also designed to treat all undefined conditions that could arise from ill controlling or hardware failure. Laboratories are generally backed up by UPS power supplies, ensuring the automatic restart and accessibility after a power blackout. The proposed security guidelines were also provided to other owners/administrators of RLs hosted in our RLMS to provide overall security of them.

### **3.2 Remote laboratories on mobile devices**

The change of the situation in ICT field came with a new technology of mobile devices (MD). These devices like smartphones or tablets bring exactly what common users need. In combination with other advantages like a small size and connectivity from almost everywhere MDs became a most fast-spreading technology of all time [22].

This situation brings a new problem to solve. The vast majority of the web pages were not created for usage on the MD. In some cases this is not a problem and the web page works fine. However, when the page contains more graphics and some technology elements (e.g. flash) it may not be displayed correctly. Remote laboratories and their control web pages were not exception, therefore, the appropriate measures had to be done to solve this problem. Three main possible methods of solution of this problem were taken into account and are described in detail below. According their analysis the best method was chosen.

**A. Mobile Web Page** - This method comes with two separate web sites for classic PCs and mobile devices. Since the mobile version is designed separately it may be completely optimized for the MD. Less graphic elements are used leading to a smaller volume of transferred data and a faster page loading. Because a content of pages is also independent there can be different information in both versions. On the other hand creation of two different versions needs more time and resources.

**B. Responsive Web Page** - A responsive web page is a same for both PCs and MDs. There are always same data transferred to the client device but an appearance of the page is varying based on a screen resolution of the device. Appearance is changed directly in a web browser which translates part of source code intended for the current resolution of device. Developer can set several versions of appearance independent on the devices type based only on the screen resolution.

**C. Standard Web Page** - This web is absolutely same both for PCs and mobile devices. Correct displaying on the MDs is achieved by a selection of a proper layout and technology of the page design. These pages usually require zooming and scrolling during their using. Even they are fully functional they are often not so user comfortable as previous mentioned types.

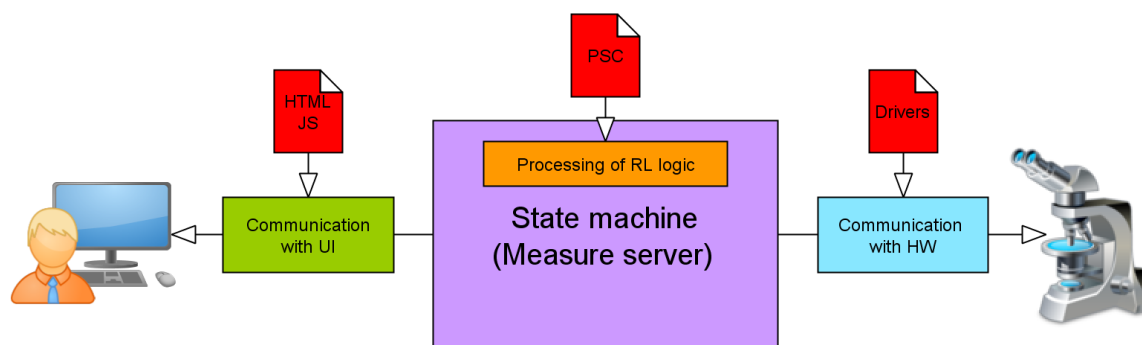
For our purposes the responsive web page was chosen as a used method for optimisation of RL's control webpage.

### **3.3 Remote laboratories development environment**

Design of the RLs was in the past a relatively complex matter [23][24]. A main problem was a compiling of control logic of the RL itself based on its flow chart logical sequence (e.g. for reaching the desired temperature) that performs the specified action (relay turn on/off the heat). This controlling logic has to secure the interactions between a remote user (client) and the controlling of the experiment at the server side (when the client presses the virtual switch on his/her screen, then the same action must follow, as it was the actual power supply button of the device).

Common standard was a creating of unique control logic, and therefore control software itself, for every single RL. Unfortunately, there were significant demands to programing skills and development time. The aim was to create more universal and complex solution. A new scheme for common RL was designed (Figure 2). Heart of this scheme is a state machine which can communicate with physical hardware, read measured values and send new values (instructions) to physical devices. On the other hand the state machine is able to communicate with end user, send him/her measured values and receive control instructions. Last main function of state machine is a transferring of data (instructions) between end user and physical hardware based on controlling logic which is provided in form of instruction file. To provide maximum

universality state machine are able to utilised library files with drivers for many physical devices and therefore can be used for new device just by adding this driver library files.



*Figure 2 Scheme of common RL software solution*

For this scheme the state machine created at Faculty of Mathematics and Physics of Charles University in Prague was used and modified to completely fit this scheme. It is called "Measure server" (MS) [25] and was updated with a many new functions. These changes of MS are part of another doctoral thesis.

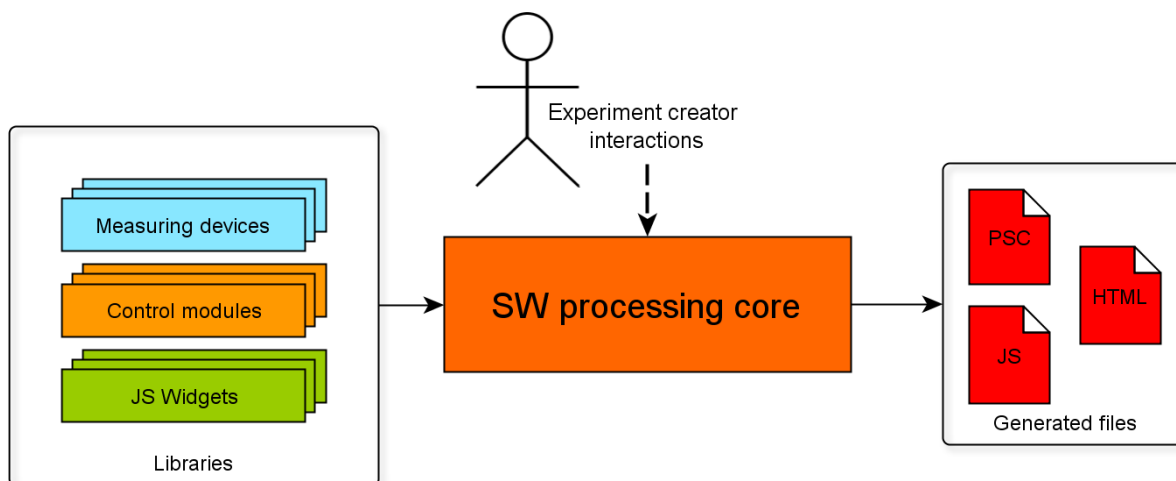
In this scheme only a three parts have to be modified to adjust specific RL. First one is a group of driver libraries for particular devices used in RL. Second is an instructions file for state machine which was marked by extension ".psc" (so called "PSC file"). Last part of the scheme which has to be usually modified is a user interface (UI) which is provided to the end user to controlling of experiment. The RL development environment was designed according to this scheme. Its main function is to install appropriate SW and drivers based on used physical hardware and help to create missing parts (PSC file and UI) of scheme as easy as possible to author of RL.

Created environment was many times modified and updated to obtain best and user friendly application. Last production version was called "Easy Remote Laboratory" (ERL) and is available in Czech and English version. ERL works as an expert system and guides user through RL creation process. It also contains methods for complete installation of all required SW, drivers and libraries to run RL from the scratch.

During the development process the main focus was pointed to keeping maximum modularity to provide further easy option to update application by new measuring devices and/or functions. Therefore, the three main object



models were created. They stand for the measuring device (Device), control module (Module) and JS web controlling element (Widget). Each of these models has its specific structure, data and methods and is assigned to appropriate library. In the case of need, any new model can be easily added by following the specified model structure.



*Figure 3 Simplified application function description*

Application core works with models and based on user interactions and answers to questions builds structure of new RL. The outputs of application are required files fitting to RL scheme. This simplified application description is depicted in object diagram (Figure 3). Final application is very complex and consists from almost sixteen thousands lines of code. Therefore, is not possible to bring detailed description of code in this work.

### **3.4 Remote laboratories diagnostics server**

Since the RLs are operable in 24/7 scheme and most of that time do not require supervision the fault of some part of the system may be very problematic and may not be discovered in a short time. Therefore, there was a need for complex diagnostic solution for the scheme of RLs. The solution with three layers of diagnostics was designed for the scheme of RLs. Each of these layers is designed to discover specific problem at RL. Diagnostic server (DS) was created based on this three layers scheme. This server was developed as a Java application which runs as a system service on the dedicated virtual server.

First layer of diagnostics is focused to communication with RL. This is a basic level of diagnostics since if there is no active communication with RL, there cannot be any other measures in operable. This layer was realized on the

TCP/IP protocol base. Second level of diagnostics is based on a broadcast from server and reporting of status. The DS sends a regular broadcast request for the status report to all connected RL after a certain time frame. Furthermore, the RL themselves report their status change automatically. All these measures ensure the availability of the table of RLs actual status at any time. Third level of diagnostics provides a deep data analysis. It monitors values from measuring devices and compare them with reference values. A malfunction of sensors can be detected by this.

Besides, the diagnostic system allows so-called automatic self-repair of an experiment at second and third level. In case of the RL failure and communication running (RL answers on the broadcast by error) the DS sends the instruction to perform a certain actions according to the type of an error.

### **3.5 Remote laboratory management system**

Due to the new trend of merging of RLs into large grids the need for a complex administrative system with full functions support for the end users and RL administrators also arose. To fill this situation the new remote laboratory management system called "REMLABNET" was designed and developed. Schemes, methods and procedures used for creation of this system are described in this chapter.

#### **3.5.1 Basic scheme**

Project of this size which should be able to fill demands of RLs across many countries could not be operating as a stand-alone server. This approach is absolutely insufficient in the matter of computing power and connection bandwidth also. This fact led to distribute blocks of system to separate virtual servers. These servers run in datacentre with optical backbone Internet connection. Separation of the system to blocks was made based on their functions with regards to optimisation of the computing power distribution. With this distribution in mind the basic scheme of RLMS was made with proposal of its functions. It can be seen in the (Figure 4).

The heart of the RLMS is a new content management system (CMS) which serves as a UI for the system administrators and users (both RL administrators and end users) also. The CMS was proposed and built as a web application with utilisation of HTML5, PHP and JS programming languages. Detailed description of this CMS can be found later in this work. Second crucial part of system is

data warehouse where all information and measured data are stored. Diagnostic server communicates with RLs and his functions are described in detail in previous chapter. Data server is responsible for obtaining of measured and statistical data from RLs and their storing in data warehouse for further usage. Last part of virtualized cloud is communication server which manages all communication between individual users.

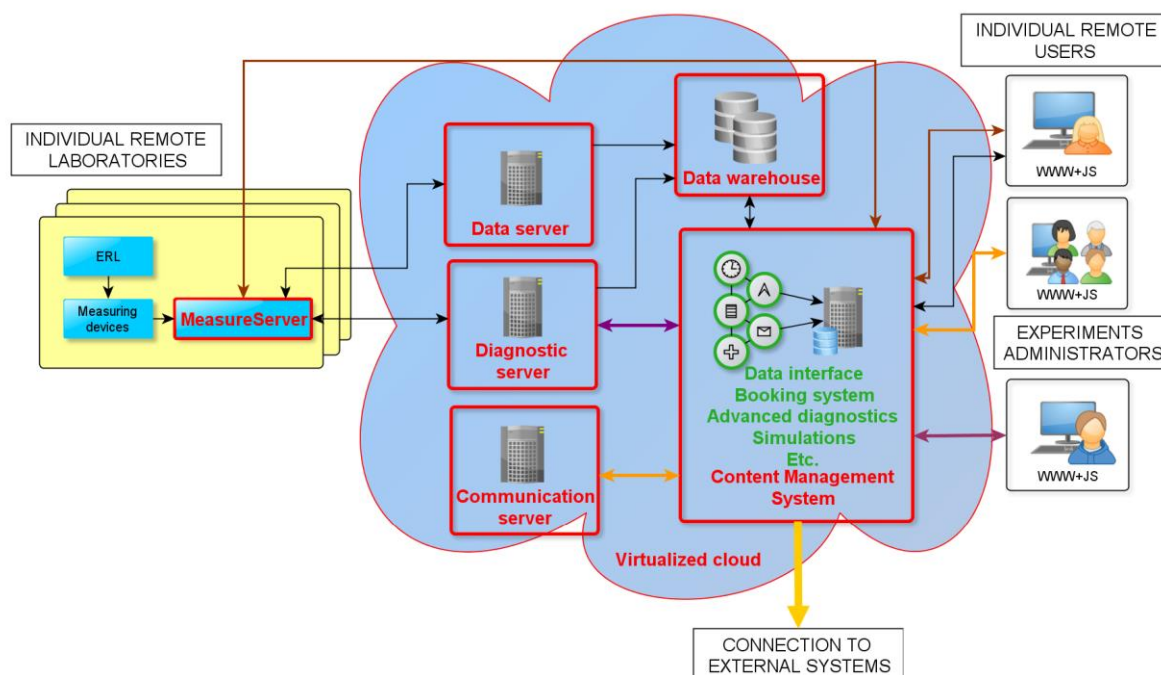


Figure 4 Basic scheme of REMLABNET RLMS

### 3.5.2 Working methods

There are four methods of accessing of RL through the RLMS. They are based on the number of users which want access same RL and the connection between these users. RL can be also accessed from external system through RLMS for which case the specific method is also present. All access methods are described below.

**Multiple users - multiple RLs** - Is the basic and most common situation, i.e. the connection of multiple users to different RLs, using RLMS.

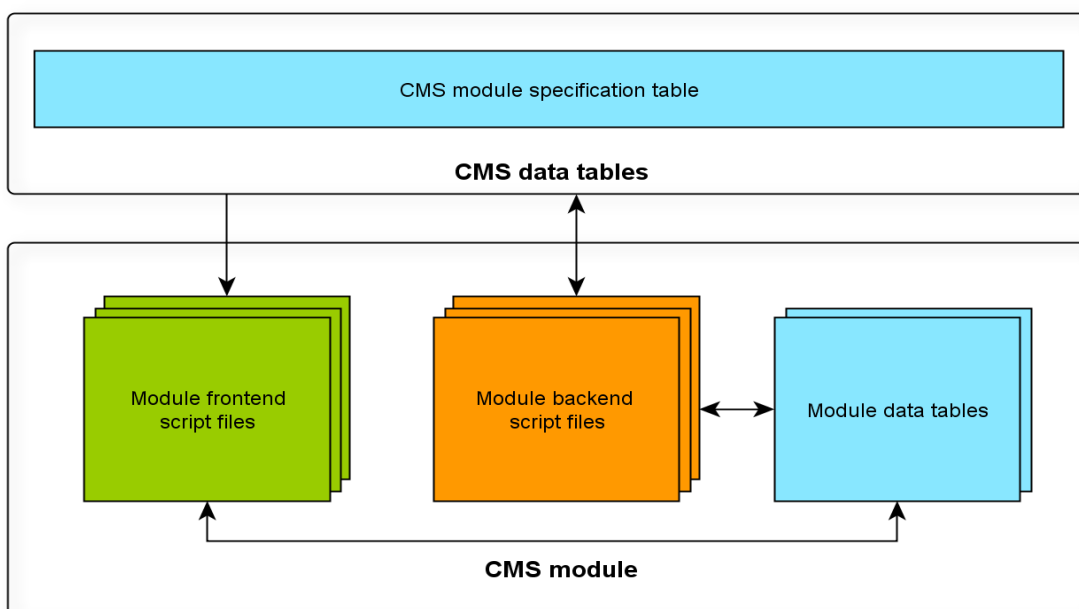
**Multiple users - one RL** – Is the connection of multiple users to one RL via RLMS. Only the first user connected to the RL has exclusive control. Each RL has specific maximum controlling time after which the controlling rights are transferred to second user in the row.

**Multiple users in virtual classroom with tutor** - It describes connection of multiple clients to a single experiment by using a virtual classroom organized via RLMS. This method was introduced in original proposal but has not been realized yet.

**User from external system - one RL** – It is the situation when the user does not access RL through RLMS but through external system which is connected with RLMS by one of created federalisation APIs (described in Chapter 3.5.5).

### 3.5.3 Content management system (CMS)

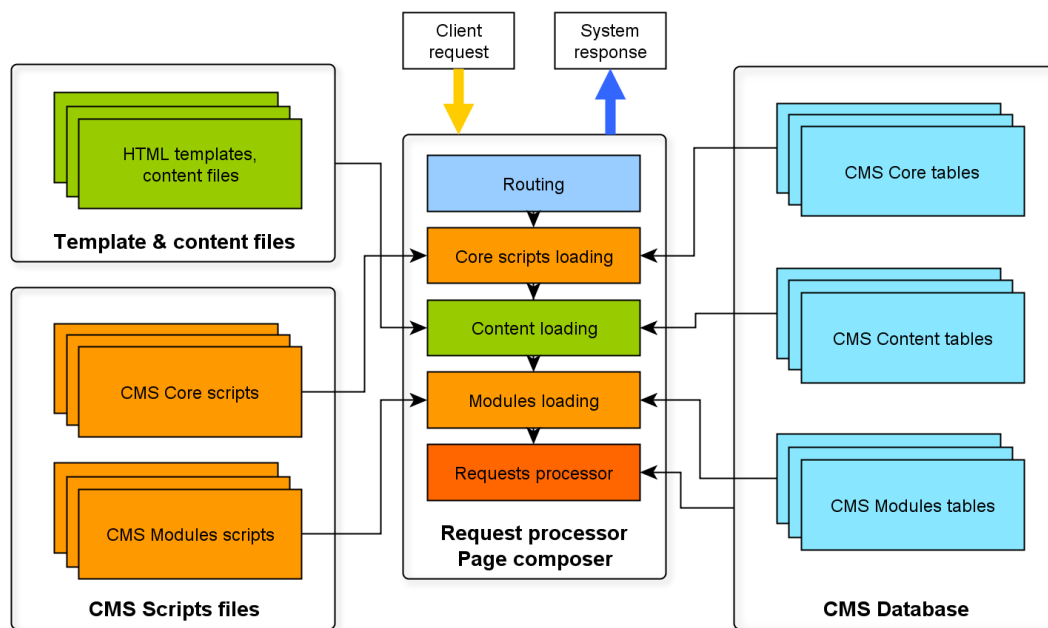
RLMS has to deal with a big amount of data. This amount is multiplied when we considered using of RLMS at EU level. It is impossible to manage these data without proper and intuitive administration interface. Several commercial content management systems (CMSs) were considered as a candidates for this place but none of them was sufficient for this special use case. Because of this fact the new content management system was designed and created as a heart of new RLMS. CMS was developed as a module-based system. It means that there is a unified specification for modules interface which ensuring possibility to develop and easy add new module based on current RLMS needs. Basic modules were developed together with system itself. Unified scheme of module is shown in the scheme below (Figure 5).



*Figure 5 Basic module scheme*

Main information describing module is stored in overview table in DB. Each module must have the backend part which serves for its activation and settings and consist of one or more PHP script files. There may be another group of scripts for frontend. Module can also consist of own DB table/s for storing of setup information or another data produced by module.

System consists of hundreds of script files serving for various functions and it is impossible to describe them all in detail. Therefore, only the block scheme of system core and common modules are depicted in diagram below (Figure 6).



*Figure 6 CMS core scheme*

Main function of system core is a correct processing of user requests based on database information and modules functions. These requests can be processed on background with no obvious results but mostly it leads to changes in UI. All information which is processed by system is saved to correct place in DB structure. These structure are growing with new modules and functions provided by system.

### **3.5.4 Special modules**

This chapter contain description of methods used for special modules which were designed for processing of special functionalities of the system. These modules were developed subsequently according to system module architecture.

### **Quick-chat module**

This module is intended to quick messaging between the users which are connected to one RL. It does not utilize the standard system SQL DB but is based on real-time Firebase NoSQL database where data is synced across all clients in real-time, and remains available when the user goes offline. The Firebase Real-time Database (FRDB) is a Google cloud-hosted database [26]. Data is stored in JSON format and synchronized in real-time to every connected client. New user messages are persisted locally, and even while offline, real-time events continue to fire, giving the end user a responsive experience. When the user regains connection, the FRDB synchronizes the local data changes with the remote updates that occurred while the client was offline, merging any conflicts automatically.

### **Diagnostics module**

This module processes all diagnostics data across whole system. It communicates with diagnostics server (Chapter 3.4).

### **Data analysis module**

This module can be also considered as a measurement history module. Backend part is intended for storing of measured user data to the database. The measured data are stored locally at RL's server. Immediately after the end of measurement the Measureserver create connection with RLMS data server and save measured data through FTP protocol. These data are in the form of XML file and are marked with the unique MAC address of RL and the exact time where the measurement takes place. Backend part of the module contains CRON task which is repeatedly processed in one minute interval. This task creates connection with FTP storage and check the existence of the new data file. If the data is found the module reads time of measurement and the RL identification and compare them with the sessions stored in database. It identifies exact user which was connected and performed particular measurement and assign him/her to the measured data. After that, it parses the XLM file and save measured data to the RLMS database with all supplement information (user and session identification). This process takes place in the few minutes according to the CRON cycle and the volume of measured data. After this short time the measurement is properly stored in the RLMS and the user can access it for further data analysis. It is secured by the frontend part of the module. It loads the data from DB and displays them into the interactive chart. For the visualisation

the Google Charts API is used. Users are able to filter data and zoom only the part of the chart. They can also read data values directly from the chart by hover the cursor to the plotted curve.

### 3.5.5 RLMS Federalisation

Federalisation itself requires rather complicated changes in RLMS structure. In (Chapter 1.3) we describe general criteria, according to them the two new communication interfaces was designed. First one is mainly intended for sharing RL with the European project GoLab [27] and the associated knowledge management system Graasp [28]. Second interface is based on the Learning Tools Interoperability (LTI) protocol, which is primary designed to connect learning systems such as a learning management system (LMS) with external service tools in a standardized way. This generally used standard was adopted by main learning platforms like a Moodle, Google Scholar, etc. Developed scheme and used methods for these interfaces are described below.

#### GoLab federalisation interface

According to architecture and technical solution of RLMS system we decided to choose Smart Gateway (SG) integration for connection with Go-Lab. It is one of the options which Go-Lab provides for connection with RL and RLMSs.

There were two main tasks which had to be done for the integration of Smart Gateway interface with our RLMS. First was a creation of a new HTTP API ensuring creation of communication canal between RLMS and SG. Second task was a creation of a function blocks representing particular RLs. Both of these parts are described below.

Since the RLMS is based on PHP programing language, the API was based on the same technology. RESTful API was designed and created which provides several methods. First group of methods intended for handshaking, identification of version and capabilities of used interface. Next group of methods serves for obtaining of information about and access to provided laboratories. As an example the “**reserve**” method can be mentioned. It performs a reservation and returns both: a reservation identifier and a URL to be loaded.

HTTP request: POST BASE\_URL/reserve?context\_id=IDENTIFIER

Request arguments: request {  
laboratory\_id (string): unique identifier for the lab,  
username (string),

```

institution (string, optional),
general_configuration_str (string, optional),
particular_configurations (string, optional),
...
back (string, URL): address to send back the user once finished,
}
Response example: {   "load_url": "http://www.remlabnet.eu/...",
                    "reservation_id": "56f9697b10333" }

```

The response contain reservation\_id object. It is a unique code generated by RLMS for the identification of particular access to the RL. This code also serves as session identification. All information gathered during the usage of experiment are bound to this code and stored into data warehouse. All methods allow creation of Smart Gateway widget which is used by Go-Lab or other LMS for connection with our RMLS. Widget ensures proper handshake of systems and basic HTTP authentication also allows processing of all provided information [29].

The RLMS was not designed for the federalisation purposes in the first place. Therefore, the structure of the RLs in RLMS had to be accommodated to cope with new demands. A new module for the transformation of particular RLs to function blocks intended for the federation sharing had to be created.

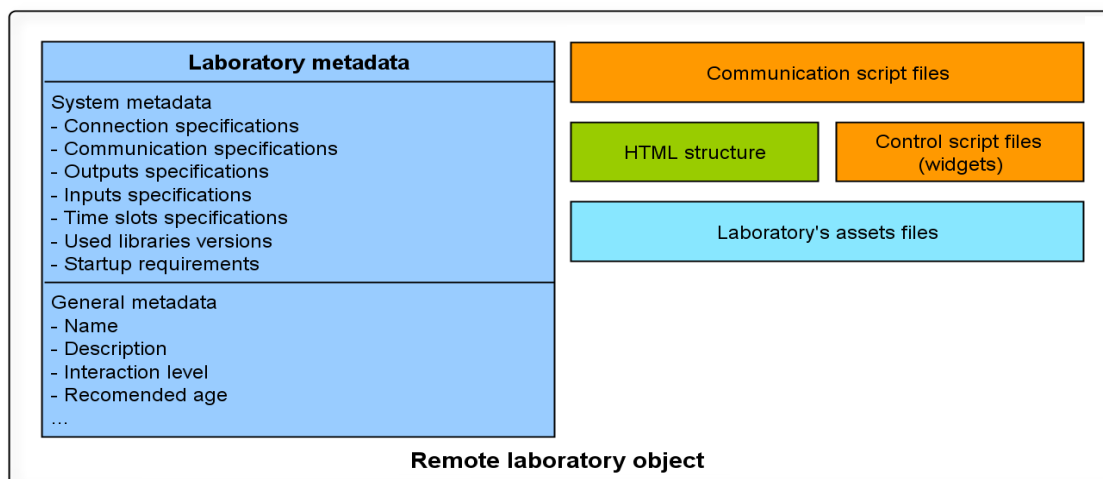


Figure 7 Basic structure of RL object

The main function of the module is executed in real time when the request for sharing through SG occurs. The module takes information stored in DB and script files for requested RL and transforms them into an object with specific structure which is necessary for federation purpose. Created object has precise



specifications of all main parameters, inputs, outputs and controlling elements of RL. Structure of this object can be seen in the Figure 7. This object can be then easily transferred to the consumers system and operated according to remote user needs. Since these RLs objects are universal and can be easily modified based on consumer systems they may be used in other cases of RL federalisation. This approach was therefore adopted as a main way of RL sharing in our RLMS.

### **LTI federalisation interface**

Smart Gateway interface which is described above is sufficient for federalisation with project GoLab but there are also some disadvantages. From this reason new API for adopting of Learning Tools Interoperability (LTI) specification was designed and developed. LTI is a specification developed by IMS Global Learning Consortium. The principal concept of LTI is to establish a standard way of integrating rich learning applications (often remotely hosted and provided through third-party services) with platforms like learning management systems, portals, learning object repositories, or other educational environments [30]. This approach was adopted by many big systems like a Moodle, Google course builder and many more [31].

New API was created according to the LTI specification. Compared with previous GoLab solution LTI requires complex handshaking between both systems. Before the RL is shared large amount of data is transferred describing consumer system, creating session and particular user accessing to laboratory. All data are processed and saved to RLMS database for further analysis. API implements new OAuth security standard for connection between RLMS and consumer system [32]. This mechanism is used by companies such as Google, Facebook, Microsoft and Twitter to permit the users to share information about their accounts with third party applications or websites.

As all other functionalities LTI integration was designed as a RLMS module according to developed structure also. For the sharing of RL same principle of transformation RL to the objects was used as at GoLab federalisation. Besides federalisation itself LTI module ensures processing of all information transferred between both systems. It creates virtual account of consumer remote user in RLMS DB and save all user preferences, measured data and statistics into it. Therefore, when the same user is connected again all his/her data and settings are provided to him/her.

## **4. MAIN RESULTS OF THE WORK**

All performed work was focused on fulfilling the goals of the PhD thesis (Chapter 2.). For each of these goals results was created mostly in the form of software project. Next main outputs of the PhD thesis are given.

### **4.1 Remote laboratories development environment**

First tasks of my thesis were “bringing RL to layman in the field” and “creation of remote laboratories development environment”. These tasks are connected since the right accomplishment of the second task was also fulfilling of the first one. According to proposal (Chapter 3.3) new RL graphics development environment called “Easy Remote Laboratory” (ERL) was created. This environment is easy to use even for common PC users. It allows creation of RLs to laymen in the field. ERL is still enriching with new features according to trends and field development. Current stable version which is completely operable is described in this chapter.

#### **4.1.1 ERL in general**

For practical reasons the remote laboratories are divided into three categories according their complexity. First category “Library of RLs” contains basic experiments from which the user can choose. After selection, the experiment is loaded and the RL is fully operable. Another two categories (basic level and advanced level) are described below.

#### **4.1.2 Basic level of RL**

The creation of basic level RL starts at welcome screen where the first step is a selection of used HW. Currently, there are three types of HW to choose. All of them are "Internet School Experimental System" (ISES) [10] based (USB connected, PCI and Professional). ERL also allows using of other HWs by adding their specification as a library files. When you click at one of them the screen for the selection of measuring modules occurs (Figure 8). When finished, user may continue pressing the next button. If some of the output modules were selected, the program will ask for details of the setting. After confirming the selected values the window with website design appears.



Figure 8 Modules selection window for basic level of RL

The main purpose of this screen is to choose the representation of the values from individual modules which were chosen in the previous step at the web page. It is done by the "Catalogue of activities". From it the way of the display of the value of the selected module can be choose (i.e. which data representation will be used). After the selection of a desired activity a window with settings is shown (Figure 9). Its content depends on the chosen activity. It is necessary in this window to set properly all parameters of the widget. Most of the parameters are already filled, so just check whether they correspond to our intention during measurements.

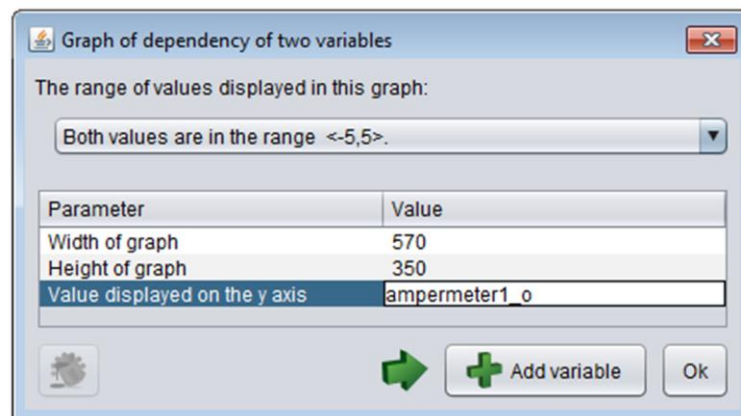


Figure 9 Activity setting window

After pressing the “Finish” button the program goes back to the welcome menu. At this moment the experiment is already operational, and we can start using it.

### 4.1.3 Advance level of RL

The advanced level of RL compiling is based on the composing of individual steps of the RL behaviour flowchart by using of the pre-prepared control blocks. In this way it is possible to assemble very complex control logic program for complex RL. This method requires a certain amount of creativity and logical thinking concerning the sequence of actions of the experiment.

First and the last step of advanced design are similar to the basic design, we have to select the modules and design the website. Between these two steps the window for advanced level design is placed (Figure 10). Its left part is a tree structure representing the control logic of the experiment. On the right side a list of blocks that can be inserted into a tree structure and a list of variables are placed.

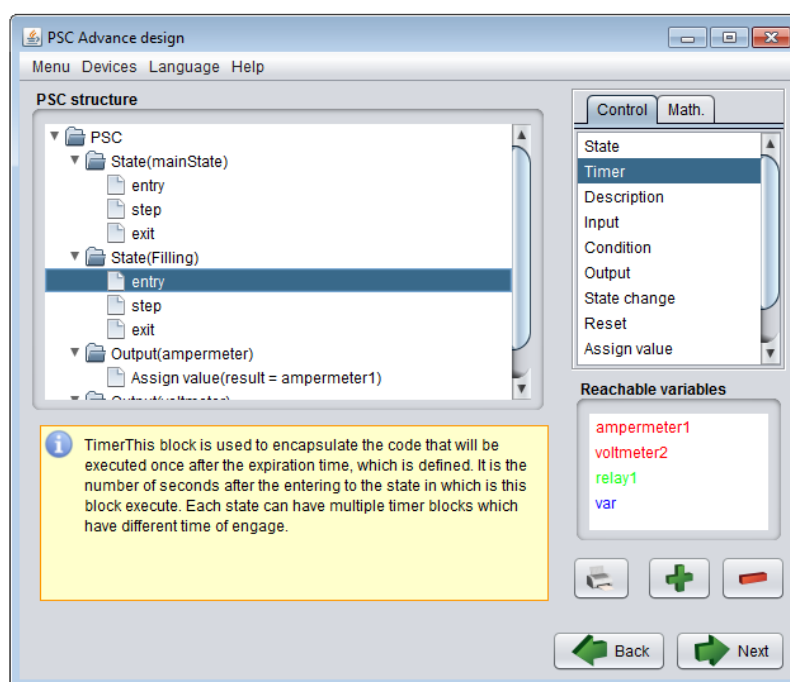


Figure 10 Advanced design window

Compiling of control logic is performed by selecting the appropriate block from the menu and then clicking to the point of the tree, where the block should be placed. Each block has individual rules for inserting into the tree and may not be placed arbitrarily. The “State” block is the main block of the entire design

representing certain state of the experiment. For example in “The water level control” RL we distinguish states such as: filling, draining and waiting for switching of the probe. Activities of the individual steps are obvious from their names. For a new experiment we have to consider all actions present in the experiment and divide them into similar states. The best way is to create a flowchart diagram of the RL run.

In the advance mode there is one difference during the website design. It is an option to export RL into RLMS. When the user choose this options instead of finishing and installing RL locally, the package representing created experiment and its control webpage is generated. This package can be uploaded into RLMS witch serves as an easy way to add new RL. It does not require any additional programing only inserting of description and supplement information about experiment.

*Summary of the subchapter “4.1 Remote laboratories development environment”:* This subchapter fulfils the goal number 1 and 2. Created environment ERL brings new approach for the construction of RLs. This new approach omits the demands for any programing during the RL creation and opens this activity to common people. The modularity and universality of the ERL called for the scientific approach during the development and propose of the new mechanics and algorithm designed for this environment.

## **4.2 Mobile devices support**

Due to massive spread of mobile devices next task of my work was an enabling of usage RLs on this platform. Several optimizations was taken and implemented into created RLs development environment. Thanks to these optimizations RLs created by ERL are now fully operable at all types of mobile devices. Results of the preformed optimizations are described in this chapter.

### **4.2.1 Original RL website**

Control web pages produced by the first version of the ERL were optimized for a wide screen. As controlling elements JavaScript widgets are used. Each element is designed as a stand-alone library and added to the web page like a building block. This structure of page can be easily modulated for a various types of RL.

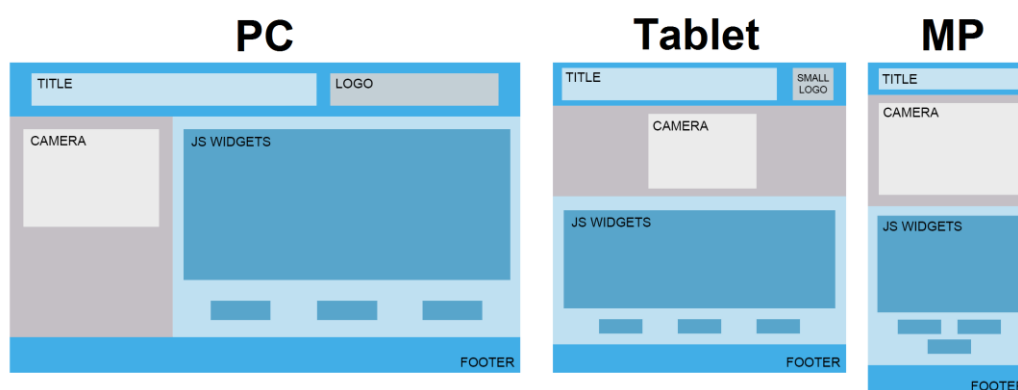
Main problem comes with a low resolution and screen size of mobile devices. Layout of original page was not suitable for mobile resolution. Also controlling

widgets were too big for a small screen. According to this problem a new version of ERL was created. This version takes into account growing influence of mobile devices and completely change output web page format. Necessary changes are described in the next chapter.

#### 4.2.2 Few steps to a responsive web

According to working methods analysis (See chapter 3.2) the responsive web page was chosen as a proper way to ensure operability of RL at mobile devices. All necessary dimensions were entered as a proportion of the page. This setting ensures correct displaying on all higher resolutions. However, if we kept this setting for the mobile devices, controlling elements would be very small and not suitable for a comfortable usage. At this point CSS media queries come.

Media queries are simple filters that can be applied to CSS styles. They make it easy to change styles based on the characteristics of the device rendering the content, including the display type, width, height, orientation and even resolution. This syntax allows the creation of rules that can be applied depending on device characteristics [33]. By using of this technology three different page layouts was designed for the different screen resolutions. Layout proposal can be seen in (Figure 11).



*Figure 11 Design of page layout for different resolutions*

For each layout specific breakpoints were chosen. Those points mark exact range of screen resolution for which the layout is used. Breakpoints were chosen in order to divide screen resolution to PCs, tablets and mobile phones (MP). However this is not a strict rule. If a tablet is used in a landscape mode, there may be a sufficiently high resolution and the layout for PCs screen is used.

Users can also use a MP with sufficient resolution for displaying of the tablet layout. Chosen ranges are – PC: (+1001) px; Tablet: (1000 – 491) px; PM: (490 - 0) px. The last but no least step in the page transformation arises from a data transfer saving at the MDs.

After optimisations the test was performed using the “W3C mobileOK Checker” [34] with a result of 94%. Nature of the web page with the RL prevents to achieve 100%. Nevertheless, reached score is a very good result particularly in comparison with the starting points (10%). RL fully optimized for the mobile devices are now produced by the new version of ERL development environment.

*Summary of the subchapter “4.2 Mobile devices support”: This subchapter fulfils the goal number 3. The maintaining RLs in the actual trend could not be real without the full accessibility from the mobile devices. These optimisations needed not only the analytics but scientific approach as well, to find the most suitable optimisation methods for this specific type of technology. The novelty is not the responsive web approach which is commonly used but its utilisation and optimisation for the controlling elements of RLs which was not realised before.*

### **4.3 Diagnostic server for RLs**

Before the creation of the RLMS for European usage the proper function of all RL had to be ensured. Therefore the first step of RLMS creation was a diagnostic server. This server ensures sustained operability of all RLs connected to RLMS. It is achieved by several precautions and methods of diagnostics (See chapter 3.4). Final result of the development is described below.

Created diagnostic server (DS) ensures keeping track of the status of the experiments connected to the RLMS. Depending on the activity of the experiment, its breakdown or failure the status is displayed at the access portal of RLMS. Diagnostic also allows sending commands to the RL in the case of detected faults. It's clear that DS communicates directly with measuring server at the experiment-side because only there the latest information about the availability and status of the experiment can be found [35].

The basic functionality of diagnostics is to determine whether the RL is available or not. This is accomplished in several ways. The basic feature of the experiment's availability is the list of connected IP addresses. When you start the experiment the socket connection is created with the service on the server-

side. This connection remains active until it is closed by one of the parties or one of them is disconnected. In case of malfunction occurring and experiment turning off, the service is closed, connection is lost which indicates experiment inaccessibility [36].

However an error may occur even with the RL, which has not terminated the connection, but it is not proper for measurements. For this purpose another precaution is operative, as the server service sends a regular broadcast request for the status report to all connected RLs after a certain time frame. They have to replay their current status or are considered as out of function. In this way not only fault of RL is detected, but its occupancy as well. Furthermore, the RLs themselves report their status change automatically. Log of RLs reports to diagnostics server is shown in (Figure 12). All these measures ensure the availability of the actual table of RLs statuses at any time.

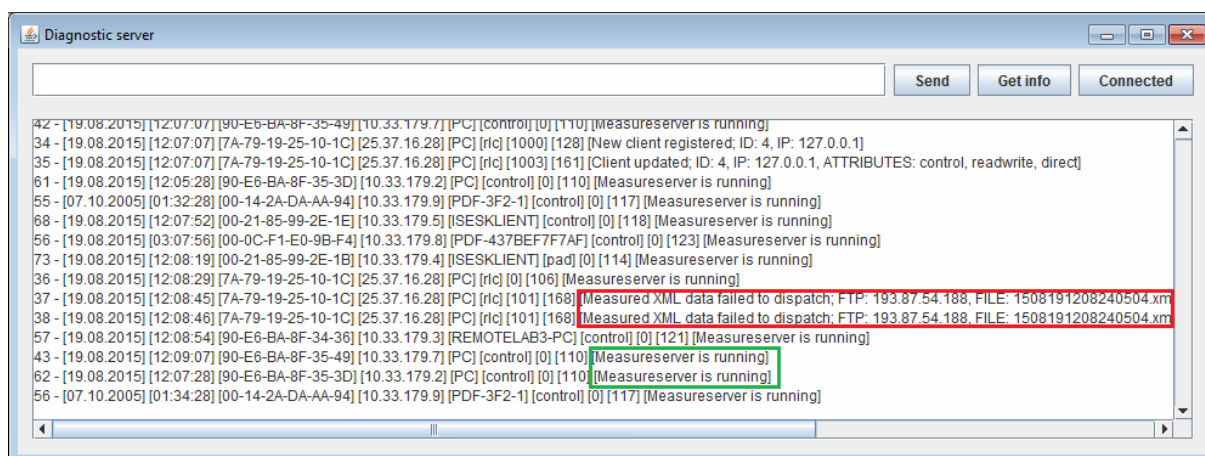


Figure 12 Diagnostic server report log (green denotes proper function, red malfunction)

Besides, the diagnostic server allows so-called automatic self-repair of an RL. In the case of the RL's failure and communication running (RL answers on the broadcast by error) the server sends the instruction to perform a certain actions according to the type of an error. One of them may be the restart of the RL or the whole computer to which RL is attached, which makes it operational in most cases. This function may be also used by RL administrator through web interface. If these or other measures don't bring the RL back to operation, the DS contacts the administrator of the RL automatically.



Diagnostic server is operable as a stand-alone application running at the virtualized server. Its functions are fully implemented into created RLMS by diagnostic module ensuring information transfer between RLMS and DS.

*Summary of the subchapter “4.3 Diagnostic server for RLs”: This subchapter fulfils the goal number 4. The continuous accessibility and reliability of RLs are their main advantages, but the most difficult to achieve. The flawless diagnostics is the key instrument to reach it. According to this claim the novelty approach for RLs diagnostic based on layers was proposed. Scientific approach was used for the composing of these new layers of diagnostic, diagnostics principles and the algorithm for automatic solving of the common defects of RLs.*

#### **4.4 Remote laboratories management system REMLABNET**

Final task of my thesis was a design and creation of remote laboratory management system itself. It was named as REMLABNET. RLMS was created as a web portal based on HTML5, PHP and AJAX technologies. Many functions were designed both for users and administrators of experiments. REMLABNET is already operable and contains about twenty five experiments from three universities. RLMS was created according to the initial analysis and proposed methods (See chapter 3.5). Results of the work and final RLMS are described in this chapter.

##### **4.4.1 REMLABNET in general**

RLMS REMLABNET serves for the integration of experiments and measurement equipment from many RL covering many areas of natural sciences. In spite of their diverse interfaces used and various ICT applied, their inclusion in the system is simple enough and ensure their availability to the general pool of interested. The system is running on modern facilities and data centres that enable Europe-wide integration with guaranteed access 24/7. Multilingualism of all parts of the system is a commonplace.

Modular system enables the creation of additional modules which can exploit very sophisticated instruments. The system provides an easy way to store and access the resources for measurements, instruction and cooperative research across the EU. The main focus of RLMS REMLABNET project is on the integration and management of simple experiments on the university level and even secondary education level not covered worldwide [37]-[39]. RLMS is accessible at [www.remlabnet.eu](http://www.remlabnet.eu).

#### 4.4.2 End-user interface of REMLABNET

Landing page of REMLABNET serves as an information base about project itself. Main page layout is divided into two columns with 7:3 ratio. The bigger part serves for main page content and the smaller column for the navigation and modules elements. This layout is respected across whole system.

All remote laboratories are accessible through the header menu which is always present. RL are divided according to the field of science which they cover and/or the institution which owns them. Each RL is represented as a graphical block with the name, picture and the current state of the RL. The state of RL is obtained in real time through the diagnostics module (Chapter 3.5.4) and is presented as a traffic light (Figure 13).



*Figure 13 Representation of RLs in REMLABNET*

When the user chooses required laboratory the page with basic RL information appears. Each RL can also include Motivation, Physical background, Measuring apparatus and Task assignment section. If the user already measured at this RL sidebar contains historical measurements module. After clicking on particular measurement the page with its visualisation is shown. It contains interactive plot where the user can read each particular measured value. Page also contains table/s with measured data which can be copy/pasted or exported for external analysis.

When the user presses "Run experiment" button the RL control page is shown (see Figure 14). Main part of the page contains widgets for controlling of RL. There are many types of widgets but the commonly used are buttons, scrollbars, value displays, graphs and data exports. Each RL's control page is customised to

its purpose. User can observe the activity carried out by RL through the live video stream module at the sidebar of the page. Beside video and navigation menu sidebar also contains other modules.



Figure 14 Remote laboratory control page in RLMS

Sidebar also contains RL rating module. It could be used for leaving of feedback for current RL. All feedbacks are provided to the RLs administrators for possible improvement of their RL.

If the connected user has a role of the RL administrator main menu contains items for administration and adding of new RL. After clicking at administration option the page with blocks representing RL owned by user appears (Figure 15).

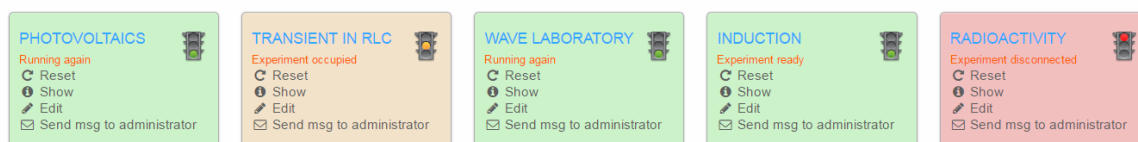


Figure 15 Representation of RLs in administration interface

Colour of each block represents the current state of RL according to diagnostics. Administrator can remotely restart RL by clicking on this option if there is any problem. Diagnostic module and server is used for this (See chapter 3.5.4). Administrator can also edit information and supplementary materials. Sidebar at this page also contains the "Quick chat" module which serves as a support for administrators or for sharing of system update information.

RL administrator can also add new RL by this option in main menu. This process is divided into four steps where he/she enter all required and

supplemental information about RL. At the last step the files containing specification of controlling widgets of RL are uploaded. These files could be programmed manually or generated automatically by graphical development environment ERL (See chapter 4.1). Because the uploaded files contains script libraries which are included in the RL control page all of them has to be approved by REMLABNET administrator. This measure is introduced to prevent of inserting malicious script into the RLMS system, despite the fact that the RL administrator user role is assigned only to the verified and trusted person.

#### **4.4.3 Backend interface of REMLABNET**

Backend administration interface is intended for adding/editing of RLMS content. This interface is only accessible for RLMS administrator with special login credentials. Administration interface contains eight main modules in menu. Each of them contains other options in submenus. The content and functions of main of them is described below.

**Content management** module is intended for adding and editing of all informative static pages and menu at the RLMS frontend. Administrator is able to edit options in main menu and add content for each of them. Content of the pages is edited in WYSIWYG editor but could be also added as a HTML code. For each of the page the access rights could be set to restrict access for specific users' role. Content could be inserted in multiple versions according to the languages. If the version for one of the supported languages is not provided this page is not accessible in this language mutation.

Module **Users and rights** contains list of all registered users with all information they entered during registration (except password). Administrator is able to edit their information and change the user role for obtaining of higher/lower access rights. User account could be also deleted by administrator in this module.

Option **Modules** contains list of all modules installed in the system. They could be disabled/enabled from this list. Particular module setting is also accessible from this menu. This setting comes from the module specification and backend script files. Last module is **Web settings** which contains basic options like database connection and domain settings. It also contains languages settings where the language could be added/edited/deleted.

#### 4.4.4 REMLABNET federalisation features

According to the world trends of federalisation and interoperability of RLMSs REMLABNET comes with two standardized interfaces for systems connection and RL sharing. It utilized SmartGateway and LTI standards. Technical solution and used methods of these interfaces was described earlier (See chapter 3.5.5). Both of the interfaces are fully operable and are used for RL sharing.

SmartGateway interface is currently used for connection with knowledge management system (KMS) Graasp [40] which is a part of GoLab project [41]. Most of the RL contained in REMLABNET are shared with Graasp at this moment. Administrators of RLs are able to turn on this function during editing of their RL. After that, the new RL is registered into Graasp at background. RL is transformed into the specific block which is suitable for sharing. The OpenSocial gadgets link [42] is generated and provided to the administrator. He/she is able to access his/her RL at the Graasp system and adjust all information which he/she wants by this link. After that the RL is accessible for all Graasp users without any other registration at REMLABNET site.

LTI interface is free to use for all RL administrators according to their needs. Since the LTI is globally supported by many LMS [30], it is very easy and useful way how they are able to add RLs into these systems without any supplementary knowledge and work. With this information he/she could easily add his/her RL into the systems supporting the LTI. Since the LTI fully support sharing of users' metadata, all services which are accessible for REMLABNET users is also provided to the users of connected system.

*Summary of the subchapter "4.4 Remote laboratory management system REMLABNET": This subchapter fulfils the goal number 5. The design of the RLMS system is obviously not a trivial matter. This activity requires scientific approach and analysis of all the connections and possible states of system parts. This fact is empowered by the modularity of the system design itself. Created system brings novelty in all the designed structures and principles of the work with RLs. The most advantage of the REMLABNET system, compared to others, is its scale and complexity. As a combination with ERL it creates a complex solution not only for the managing and global sharing of the RLs but also for their creation and cross-device accessibility. This complexity makes REMLABNET unique compared to other systems.*

## **5. CONTRIBUTIONS OF THE WORK**

The presented thesis is focused on the rising trend of RLs. This field starts to be important part of the research and teaching process as well. Goals of the thesis were aimed on the creation of the complex system covering all needs of this progressive technology and bringing it to the laymen in the field. The major intention of the project REMLABNET was to exert a high level of implementation and standardisation to be a partner to similar systems, emerging across the EU. Let us summarise the benefits of each result.

### **5.1 ERL – development environment for remote laboratories**

The graphical development environment Easy Remote Laboratory (ERL) enables a new way of compiling controlling problems for RLs by the layman in the field of software development. The creation of RL is rather demanding activity, as it requires the knowledge of physics, electronics and the software engineering. ERL environment removes the programming barrier and enables focusing on the building of physical HW only. ERL could be used to the creation of basic RLs but the RLs with very complex control logic also. Thanks to the tips and help bars there is no need for any system control training. The user is guided through the process of RL creation like in expert system.

ERL was already used for the creation of control logic of majority of RLs included in the RLMS REMLABNET. It is about twenty-five RLs at this moment and new ones are still adding. RLs created by the ERL have a full support and can be used on all standard mobile devices.

### **5.2 REMLABNET open remote laboratory management system**

RLMS REMLABNET was proposed and developed as a main task of this thesis. It was aimed as a centralisation system for RLs developed at Czech, Slovak and other European universities. It is first system of this kind developed in Czech and Slovak republic and even one of the first developed across the Europe. REMLABNET is an open system allowing anybody to use RLs included in it. It also provides opportunity to RLs administrators and creators to include their RLs to it with no fees or other financial demands.

REMLABNET does not only serve as a centralisation point of RLs but brings many features and services both for the end-users and RLs administrators also. As an example of services provided to administrators the advanced diagnostics

could be named. It ensures fulfilling one of the main advantages of RLs which is a 24/7 accessibility. System brings tools for the communication with RLs users helping the administrators stay in touch with them and possibly improve their RLs according to end-users feedbacks. It also serves as a propagation canal of RLs not only for local users but users across whole Europe thanks to the federalisation modules.

During the creation of REMLABNET, we were asked for cooperation in the Go-Lab project which is a research project co-funded by the European Commission within the 7th Framework Programme (FP7). It stands for Global Online Science Labs for Inquiry Learning at School. The Go-Lab Project opens up remote and virtual laboratories to encourage young people to engage in science topics and experience the culture of doing science by undertaking active guided experimentation. REMLABNET was connected with a Go-Lab Portal which offers school teachers and students the opportunity to conduct inquiry learning activities for scientific problem solving. Inquiry learning is supported by personalized scientific experiments with online labs from REMLABNET and supportive inquiry learning apps.

Another strong advantage of REMLABNET is the LTI standardisation. By adoption of these standards the system is able to easily share the RLs with other systems with maintaining of all functionality. This function could be very useful for all RLs owners who would like to include their RLs to other systems but have no necessary programming knowledge to achieve this task. They are now able to easily turn-on LTI functionality in REMLABNET administrator panel and share their RLs to systems like a Moodle or Google course builder where they want to present them to their users.

As was already mentioned REMLABNET brings many features and services for its users. But same as other systems it has to be developing continuously to react on the users' demands. According to this fact REMLABNET was developed as a modular system which allowing creation and inclusion of the new modules providing new functions. This scheme already brings its reward with a new module which was added recently. This module serves for the inclusion of simulation into the RLs. Users can study reactions of the simulated system to the change of its parameters and compare them with the real system and the real measurements. Modules like this could be and will be developed and easily added into the system thanks to its modularity.

Since the system officially launch at January 2015 there was about 14 thousands accesses to the RLs by about 8 thousands unique users. Majority of them are from the Czech, Russia, USA and Slovakia but there are also significant groups of users from UK, Spain, Germany or China. REMLABNET is completely localized into five languages at this moment and thanks to the federalisation and community translations the RLs are on average translated to another four languages which significantly helps to their spreading across the Europe.

Since hand in hand with development of REMLABNET comes lots of scientific publications it is known among the European RLs community. Because of that we recently received invitation to be part of the new project at the field of RL called LabsLand [43]. This project aiming to creation of global network of RLs shared at economy model. Our participation in this project is subject to further discussions.

Connected with the ERL the REMLABNET serves as a complex solution for creation, management and easy sharing of RLs. With many services and functions it enriches the end users experiences and encourages their interest in science and obtaining of more knowledge.



## 6. CONCLUSIONS

The presented work was focused on the field of remote laboratories. There are many RLs in the world which are created mainly by schools or some organizations. There is an effort to unite these laboratories into larger grids administered by Laboratory management systems. Also these systems start to be connected in the federative way. This approach highlights many new basic research aspects of integrating diverse remote laboratories systems associated with many challenges that are actually affronting each institution willing to wrap a pool of existing remote laboratories in a RLMS. Extending the implementation of RLMSs among universities is associated with new research challenges owing to the diversity of remote laboratory systems in terms of technical and pedagogical point.

This work was focused on the proposing and creating of complex software solution for the easy creation, managing and sharing of remote laboratories. According to the goals several tasks were done. First was a creation of graphic development environment of remote laboratories. This environment is easy to use even for common PC users. It allows creation of RLs to laymen in the field. Due to massive spread of mobile devices next task was an enabling of usage RLs on this platform. Several optimizations was taken and implemented into created RLs development environment. RLs created by this environment are fully operable at all types of mobile devices.

After the publication of created development environment I was invited by prof. dr. Dennis Lowe the Dean of the Faculty of Engineering and Information Technologies at The University of Sydney, Australia to attend the University as an affiliate, specifically as a Visiting Researcher, for the period 25 November 2013 to 9 December 2013 inclusive. During my stay I have led several seminars and presentation to introduce the ERL system and our plans to the following RLMS creation.

All other works had been directed to creation of remote laboratory management system for international usage. As a first part of this project a diagnostic server for RLs was created. This server ensures sustained operability of all RLs connected in RLMS. It is achieved by several precautions and levels of diagnostics. Final task was a design and creation of remote laboratory management system itself. It was named as REMLABNET. RLMS was created as a web portal based on HTML5, PHP and AJAX technologies. Many functions

were designed both for users and administrators of experiments. REMLABNET is already operable and contains about twenty five experiments from three universities [44], [45]. Some of proposed functions are still under development but they are not necessary for proper system function.

During the creation of REMLABNET, we were asked for cooperation in the Go-Lab project which is a research project co-funded by the European Commission within the 7th Framework Programme (FP7) [39]. It stands for Global Online Science Labs for Inquiry Learning at School. The Go-Lab Project [40], [41] opens up remote and virtual laboratories to encourage young people to engage in science topics and experience the culture of doing science by undertaking active guided experimentation. REMLABNET was connected with a Go-Lab Portal which offers school teachers and students the opportunity to conduct inquiry learning activities for scientific problem solving [46], [47]. Inquiry learning is supported by personalized scientific experiments with online labs from REMLABNET and supportive inquiry learning apps.

The Go-Lab project is supervised by the group at ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE (EPFL) leading by Dr. Denis Gillet. As a part of this collaboration we have also become part of the SCOPES project (Scientific co-operation between Eastern Europe and Switzerland) of Swiss National Science Foundation. I underwent two research stays at EPFL in 2015 and 2016 to create of common interfaces for federalisation of our systems.

Main goal of this PhD thesis was a creation of complex system for remote laboratories which could serve as a global tool both for experiment owners and end users. REMLABNET system fully accomplished this task since it is prepared for an inclusion of different RL types from arbitrary school, university or research workplace. The system is still enriched by new functions to provide ever better and better services for the laboratory administrator and their users also.

## REFERENCES

- [1] J. Garcia-Zubia, and G. Alves, “*Using Remote Labs in Education*” Ed. University of Deusto, Bilbao, ISBN: 978-84-9830-335-3. 2011 Available from:  
[http://www.weblab.deusto.es/web/weblab.content/using\\_remote\\_labs\\_in\\_education.pdf](http://www.weblab.deusto.es/web/weblab.content/using_remote_labs_in_education.pdf).
- [2] K. Azad, M. Auer, J. Harward, “*Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines*” Ed. IGI Global, USA, DOI: 10.4018/978-1-61350-186-3, ISBN: 9781613501863. 2012, Available from:  
<http://www.igi-global.com/book/internet-accessible-remote-laboratories/52730>.
- [3] ORDUNA, Pablo, Luis RODRIGUEZ-GIL, Ignacio ANGULO, Olga DZIABENKO, Unai HERNANDEZ, Diego LOPEZ-DE-IPINA a Javier GARCIA-ZUBIA. Towards a microRLMS approach for shared development of remote laboratories. In: *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*[online]. IEEE, 2014, s. 375-381 [cited 2016-02-16]. DOI: 10.1109/REV.2014.6784192. ISBN 978-1-4799-2024-2. Available from:  
<http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6784192>
- [4] FEISEL, Lyle D. a Albert J. ROSA. The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education* [online]. 2005, 94(1), 121-130 [cited 2016-02-16]. DOI: 10.1002/j.2168-9830.2005.tb00833.x. ISSN 10694730. Available from:  
<http://doi.wiley.com/10.1002/j.2168-9830.2005.tb00833.x>
- [5] ZALEWSKI, Janusz. Hands-on Software Engineering Labs via the Web: Game Changing in Online Education. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*[online]. 2013, 7(2), 243-250 [cited 2016-02-16]. DOI: 10.12716/1001.07.02.12. ISSN 2083-6473. Available from: [http://www.transnav.eu/Article\\_Hands-on\\_Software\\_Engineering\\_Labs\\_Zalewski,26,433.html](http://www.transnav.eu/Article_Hands-on_Software_Engineering_Labs_Zalewski,26,433.html)
- [6] IYOSHI, Toru a M KUMAR. *Opening up education: the collective advancement of education through open technology, open content, and*

*open knowledge*. Cambridge, Mass.: MIT Press, 2008, xx, 477 p. ISBN 9780262033718

- [7] S. Gröber, M. Vetter, B. Eckert and H. J. Jodl, “Experimenting from a distance – Remotely controlled laboratory (RCL)”. *European Journal of Physics*. 2007-05-16, vol. 28, issue 3, p. 127-141. DOI: 10.1088/0143-0807/28/3/S12.
- [8] Library of Labs. LiLa - Library of Labs [online]. [cited 2014-04-19]. Accessible from: <http://www.lila-project.org/home.html>.
- [9] Remote Farm. Remote Farm [online]. 2012 [cited 2014-04-19]. Available from: <http://remote.physik.tu-berlin.de/farm/>.
- [10] F. Schauer, I. Kuřitka, and F. Lustig, “Creative laboratory experiments for basic physics using computer data collection and evaluation exemplified on the intelligent school experimental system (ISES)”. *World Innovations in Engineering Education and Research iNEER*, USA, Special Volume, 2006, p. 305-312.
- [11] V. J. Harward et al., "The iLab Shared Architecture: A Web Services Infrastructure to Build Communities of Internet Accessible Laboratories”, *Proceedings of the IEEE*, vol. 96, 2008, pp. 931-950.
- [12] M. Tawfik, D. Lowe, S. Murray, M. de la Villefromoy, M. Diponio, E. Sancristobal, M. José Albert, G. Díaz, M. Castro, “Grid Remote Laboratory Management System - Sahara Reaches Europe,” *Proc. 10th REV conference*, 2013, Sydney.
- [13] The iLab Project. *The iLab Project* [online]. USA: MIT, 2017 [2017-02-16]. Accessible from: <https://wikis.mit.edu/confluence/display/ILAB2/Home>
- [14] Remote Labs Enriching digital education. *Labshare* [online]. Sydney: The Labshare Institute, 2017 [2017-02-16]. Available from: <http://www.labshare.edu.au/home>
- [15] ORDUNA, Pablo. *TRANSITIVE AND SCALABLE FEDERATION MODEL FOR REMOTE LABORATORIES*. Bilbao, 2013. Doctoral Thesis. UNIVERSIDAD DE DEUSTO. Led by: Dr. Javier García Zubía.

- [16] MAITI, Ananda. NETLab: An online laboratory management system. In: *IEEE EDUCON 2010 Conference* [online]. IEEE, 2010, s. 1351-1358 [cited 2017-02-16]. DOI: 10.1109/EDUCON.2010.5492371. ISBN 978-1-4244-6568-2. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5492371>
- [17] RICHTER, Thomas, David BOEHRINGER a Sabina JESCHKE. LiLa: A European Project on Networked Experiments. *Automation, Communication and Cybernetics in Science and Engineering 2009/2010* [online]. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, s. 307 [cited 2017-02-16]. DOI: 10.1007/978-3-642-16208-4\_27. ISBN 978-3-642-16207-7. Available from: [http://link.springer.com/10.1007/978-3-642-16208-4\\_27](http://link.springer.com/10.1007/978-3-642-16208-4_27)
- [18] ZUTIN, Danilo Garbi, Michael E. AUER, Christian MAIER a Michael NIEDERSTATTER. Lab2go — A repository to locate educational online laboratories. In: *IEEE EDUCON 2010 Conference* [online]. IEEE, 2010, s. 1741-1746 [cited 2017-02-16]. DOI: 10.1109/EDUCON.2010.5492412. ISBN 978-1-4244-6568-2. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5492412>
- [19] MUROS-COBOS, Jesus L. a Juan A. HOLGADO-TERRIZA. RVLab: A server-side framework to build remote and virtual laboratories. In: *2012 9th International Conference on Remote Engineering and Virtual Instrumentation (REV)* [online]. IEEE, 2012, s. 1-8 [cit. 2017-07-14]. DOI: 10.1109/REV.2012.6293161. ISBN 978-1-4673-2542-4. Available from: <http://ieeexplore.ieee.org/document/6293161/>
- [20] M. Krbeček, F. Schauer and R. Jašek. “Security aspects of remote e-laboratories”. *International Journal of Online Engineering (iJOE)*. 2013-07-11, vol. 9, issue 3, p. 34-39. DOI: 10.3991/ijoe.v9i3.2586. Available from: <http://online-journals.org/i-joe/article/view/2586>.
- [21] Cyber security standards. *Wikipedia* [online]. San Francisco: Wikipedia, 2017 [Read. 2017-07-15]. Available from: [https://en.wikipedia.org/wiki/Cyber\\_security\\_standards](https://en.wikipedia.org/wiki/Cyber_security_standards)
- [22] DEGUSTA, Michael. Are Smart Phones Spreading Faster than Any Technology in Human History? In: *MIT Technology Review* [online]. May 9, 2012 [cited 2017-02-16]. Available from:

<http://www.technologyreview.com/news/427787/are-smart-phones-spreading-faster-than-any-technology-in-human-history/>.

- [23] S. Williams, R. Blanchard, A. Mohammed, M. Bliss, R. Pancholi, M. Clowes (2013) THE DEVELOPMENT OF A REMOTE LABORATORY FOR DISTANCE LEARNING AT LOUGHBOROUGH UNIVERSITY, Proceedings, *5TH INTERNATIONAL CONFERENCE ON EDUCATION AND NEW LEARNING TECHNOLOGIES*, International Association of Technology, Education and Development (IATED), 2013. pp. 4342-4349. ISBN 9788461638222.
- [24] M. Krbeček, F. Schauer, and I. Zelinka. “Possible utilization of the artificial intelligence elements in the creation of remote experiments”. *International Journal of Online Engineering (iJOE)*. 2014, vol. 10, issue 1, p. 46-52. DOI: 10.3991/ijoe.v10i1.3110. Available from: <http://online-journals.org/i-joe/article/view/3110>
- [25] GERŽA, Michal, František SCHAUER a Ivan ZELINKA. Artificial Intelligence in ISES Measureserver® for Remote Experiment Control. In: *International conference on prediction, modeling and analysis of complex systems* [online]. Ostrava: Springer Verlag, 2014, s. 411-420. DOI: 10.1007/978-3-319-07401-6\_41. ISBN 978-331907400-9. ISSN 21945357. Available from: [http://link.springer.com/10.1007/978-3-319-07401-6\\_41](http://link.springer.com/10.1007/978-3-319-07401-6_41)
- [26] MA, Francis. What’s new from Firebase. In: *Firestore* [online]. CA: Google, 2017 [cit. 2017-07-15]. Available from: <https://firebase.googleblog.com/2017/05/whats-new-from-firebase-at-google-io.html>
- [27] Gillet, D.; Vozniuk, A.; Rodríguez-Triana, M. J.; Holzer, A.: Agile, Versatile, and Comprehensive Social Media Platform for Creating, Sharing, Exploiting, and Archiving Personal Learning Spaces, Artifacts, and Traces. In: *Proceedings of The World Engineering Education Forum, Publication* Publisher: The World Engineering Education Forum, Seoul, Korea, 2016.
- [28] GILLET, Denis, María Jesús RODRÍGUEZ-TRIANA, Ton DE JONG, Lars Bollen BOLLEN a Diana DIKKE. *Cloud Ecosystem for Supporting*

*Inquiry Learning with Online Labs: Creation, Personalization, and Exploitation*. Experiment@ International Conference: IEEE Xplore, 2017.

- [29] Rodríguez-Triana, M. J.; Holzer, A.; Vozniuk, A.; Gillet, D.: Orchestrating Inquiry-Based Learning Spaces: an Analysis of Teacher Needs. In: Proceedings of the *14th International Conference on Web-based Learning, ICWL 2015*, Publication Publisher: Springer, Guangzhou, China, 2015.
- [30] Learning Tools Interoperability. *IMS Global Learning Consortium* [online]. Lake Mary, FL 32746 USA: IMS Global Learning Consortium, 2017 [cit. 2017-07-15]. Available from: <http://www.imsglobal.org/activity/learning-tools-interoperability>
- [31] F. Jurado and M. A. Redondo, "Learning tools interoperability for enhancing a distributed personal learning environment with support for programming assignments," *2014 International Symposium on Computers in Education (SIIE)*, Logrono, 2014, pp. 87-92. doi: 10.1109/SIIE.2014.7017710 Available from: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7017710&isnumber=7017689>
- [32] Understanding OAuth: What Happens When You Log Into a Site with Google, Twitter, or Facebook. *LifeHacker* [online]. Gizmodo Media Group, 2012 [cit. 2017-07-15]. Available from: <http://lifelhacker.com/5918086/understanding-oauth-what-happens-when-you-log-into-a-site-with-google-twitter-or-facebook>
- [33] LEPAGE, Pete. Use CSS media queries for responsiveness: *Web Fundamentals*. In: *Google Developers* [online]. 2014-09-12 [cited 2016-02-16]. Available from: <https://developers.google.com/web/fundamentals/layouts/rwd-fundamentals/use-media-queries>.
- [34] W3C mobileOK Checker. *World Wide Web Consortium (W3C)* [online]. 1994-2010 [cited 2016-02-16]. Available from: <http://validator.w3.org/mobile/>.
- [35] M. Krbeček and F. Schauer. Communication and Diagnostic Interfaces in Remote Laboratory Management Systems. *International Journal of Online Engineering (iJOE)*. 2015, vol. 11, issue 5, p. 43-49. DOI:

<http://dx.doi.org/10.3991/ijoe.v11i5.4926>. Available from: <http://online-journals.org/index.php/i-joe/article/view/4926/3600>

- [36] F. Schauer, M. Krbeček, L. Tkáč and M. Ožvoldová. Remote diagnostics of remote laboratory – on example of Joule’s experiment as a probe into microworld. *REV2016: 13th International Conference on Remote Engineering and Virtual Instrumentation*, Madrid, Spain 24 - 26 February 2016
- [37] F. Schauer, M. Krbeček, P. Beňo, M. Gerža, L. Pálka, and P. Špilakova. “REMLABNET - open remote laboratory management system for e-experiments”. *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2014, vol. 2, issue 4, p. 268-273. ISBN 978-1-4799-2024-2. DOI: 10.1109/REV.2014.6784273.
- [38] Schauer, F., Krbecek, M., Beno, P., Gerza, M., Palka, L. & Spilakova, P. 2015, "REMLABNET II-Open remote laboratory management system for university and secondary schools research based teaching", *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation, REV 2015*, pp. 109. ISBN: 978-147997839-7. DOI: 10.1109/REV.2015.7087273.
- [39] Schauer F. (25), M. Krbeček (15), P. Beňo (15), M. Gerža (15), L. Pálka (15), and P. Špilakova (15). REMLABNET III — Federated remote laboratory management system for university and secondary schools. *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2016, pp. 238-241. DOI: 10.1109/REV.2016.7444471. ISBN 978-1-4673-8246-5. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7444471>
- [40] Dikke, D.; Faltin, N.: Go-Lab MOOC – An online course for teacher professional development in the field of Inquiry-Based Science Education. In: *Proceedings of the 7th International Conference on Education and New Learning Technologies*, Publication Publisher: IATED, Barcelona, Spain, 2015. - Available from: <http://go-lab-project.eu/publications#sthash.z4WYuSz2.dpuf>
- [41] De Jong, T.; Sotiriou, S.; Gillet, D.: Innovations in STEM education: The Go-Lab federation of online labs. Publication Publisher: *Smart Learning*



- Environments*, 1, 3, 2014. - Available from: <http://go-lab-project.eu/publications#sthash.z4WYuSz2.dpuf>
- [42] OPENSOCIAL GADGET BASICS. *Liferay Developer Network* [online]. CA 91765 USA: LIFERAY, 2017 [cit. 2017-07-15]. Available from: [https://dev.liferay.com/develop/tutorials/-/knowledge\\_base/6-1/opensocial-gadget-basics](https://dev.liferay.com/develop/tutorials/-/knowledge_base/6-1/opensocial-gadget-basics)
- [43] *LabsLand* [online]. Spain: LabsLand, 2017 [cit. 2017-07-15]. Available from: <https://labsland.com>
- [44] Krbeček, M., Schauer, F. 2015, „Remote Experiment On Time Domain Phenomena In RLC Circuits And Their Characterization“. *TOJET: the Turkish online journal of educational technology* [online]. Turkey: TOJET, 2015, (Special 2 for INTE 2015 July,2015): 479-487. ISSN 1303-6521. Available from: [http://www.tojet.net/special/2015\\_7\\_2.pdf](http://www.tojet.net/special/2015_7_2.pdf)
- [45] Schauer, F., Ozvoldova, M., Tkac, L. & Krbecsek, M. 2015, "INCLINE-The remote experimental kit for research based teaching in the class", *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation, REV 2015*, pp. 105. ISBN: 978-147997839-7. DOI: 10.1109/REV.2015.7087272
- [46] LERRO, Frederico, Pablo ORDUÑA, Susana MARCHISIO a Javier GARCÍA-ZUBÍA. Development of a Remote Laboratory Management System and Integration with Social Networks. *International Journal of Recent Contributions from Engineering, Science & IT (iJES)* [online]. 2014, 2(3), 33- [cited 2016-02-16]. DOI: 10.3991/ijes.v2i3.3821. ISSN 2197-8581. Available from: <http://online-journals.org/index.php/ijes/article/view/3821>
- [47] SALZMANN, Christophe, Sten GOVAERTS, Wissam HALIMI a Denis GILLET. The Smart Device specification for remote labs. In: *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation (REV)* [online]. IEEE, 2015, s. 199-208 [cited 2016-02-16]. DOI: 10.1109/REV.2015.7087292. ISBN 978-1-4799-7839-7. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7087292>

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## **LIST OF SYMBOLS, ACRONYMS AND ABBREVIATIONS USED**

API – Application Programming Interface

CMS – Content Management System

CSS – Cascading Style Sheets

ERL – Easy Remote Laboratory

EU – Europe Union

GUI – Graphical User Interface

HTML – Hyper Text Mark-up Language

HTTP – Hyper Text Transfer Protocol

HTTPS – Hypertext Transfer Protocol Secure

ICT – Information and Communication Technology

IP – Internet Protocol

ISES – Intelligent School Experimental System

JS – Java Script

LMS – Learning Management System

LTI – Learning Tools Interoperability

MAC – Media Access Control

MD – Mobile Device

PHP – PHP: Hypertext Pre-processor

REST – Representational state transfer

RL – Remote Laboratory

RLMS – Remote Laboratory Management System

SQL – Structured Query Language

TCP – Transmission Control Protocol

TCP/IP – Transmission Control Protocol/Internet Protocol

UI – User Interface

W3C – World Wide Web Consortium

XML – eXtensible Mark-up Language

## PUBLICATION ACTIVITIES OF THE AUTHOR

1. KRBEČEK, Michal. *Proposal of examples of "Vee Pro" environment for purposes of Instrumentation and measuring subject education*. Zlín, 2009. 72 s. Bachelor thesis. Tomas Bata University in Zlín.
2. KRBEČEK, Michal. *Creation of multimedia interactive teaching tool with utilisation of remote experiments*. Zlín, 2011. 108 s. Diploma thesis. Tomas Bata University in Zlín.
3. Krbeček, Michal; Ožvoldová, Miroslava. Teaching tools for primary and secondary schools with using remote experiments. *Acta Facultatis Paedagogicae Universitatis Tyrnaviensis, Séria C*, 2011, roč. 2011, č. 15, s. 70-85. ISSN 978-80-8082-514-0.
4. M. Krbeček, F. Schauer and R. Jašek. Security Aspects of Remote e-Laboratories. *International Journal of Online Engineering (iJOE)*. 2013-07-11, vol. 9, issue 3, p. 34-39. DOI: 10.3991/ijoe.v9i3.2586. Available from: <http://online-journals.org/i-joe/article/view/2586>
5. M. Krbeček, F. Schauer a M. Ozvoldova. Controlling Programs for Remote Experiments by Easy Remote ISES (ER-ISES). In: *10th International Conference on Remote Engineering and Virtual Instrumentation: (REV 2013)*. Sydney, Australia, 6 – 8 February 2013, s. 110-117. ISBN 978-1-4673-6345-7.
6. Michal Krbeček, František Schauer, František Lustig “ Easy Remote ISES – Development Environment Remote Experiments” Chap. 8, *Innovations 2013*, W. Aung et al. (eds.), iNEER, Potomac, MD, USA, pp. 81 – 100, 2013.
7. M. Krbeček, F. Schauer and I. Zelinka. Possible utilization of the artificial intelligence elements in the creation of remote experiments. *International Journal of Online Engineering (iJOE)*. 2014, vol. 10, issue 1, p. 46-52. DOI: 10.3991/ijoe.v10i1.3110. Available from: <http://online-journals.org/i-joe/article/view/3110>
8. M. Krbeček, F. Schauer, P. Beňo, M. Gerža, L. Pálka, and P. Špilakova. “REMLABNET - open remote laboratory management system for e-experiments”. *2014 11th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2014, vol. 2, issue 4, p. 268-273. ISBN 978-1-4799-2024-2. DOI: 10.1109/REV.2014.6784273.

9. KRBEČEK, Michal, F. Schauer and K. Vlček. Communication Requirements of Laboratory Management System. In: *LATEST TRENDS on SYSTEMS - VOLUME II: Proceedings of the 18th International Conference on Systems (part of CSCC '14)*, Santorini, Greece, 2014, p. 686-691. ISBN 978-1-61804-244-6, ISSN 1790-5117. Available from: <http://www.europment.org/library/2014/santorini/bypaper/SYSTEMS/SYSTEMS2-56.pdf>
10. KRBEČEK, Michal and V. Vesela. Optimization of web technologies for mobile devices. In: *Recent Advances in Electrical Engineering and Educational Technologies: Proceedings of the 2nd International Conference on Systems, Control and Informatics (SCI 2014)*, Athens, Greece, 2014, p. 133-143. ISBN 978-1-61804-254-5. Available from: <http://inase.org/library/2014/athens/bypaper/ELECT/ELECT-21.pdf>
11. VESELÁ, Veronika and M. Krbeček. Comparative analysis of web animation creation methods. In: *Recent Advances in Electrical Engineering and Educational Technologies: Proceedings of the 2nd International Conference on Systems, Control and Informatics (SCI 2014)*, Athens, Greece, 2014, p. 165-168. ISBN 978-1-61804-254-5. Available from: <http://www.inase.org/library/2014/athens/bypaper/ELECT/ELECT-27.pdf>
12. Schauer, F., Ozvoldova, M., Tkac, L. & Krbecek, M. 2015, "INCLINE-The remote experimental kit for research based teaching in the class", *Proceedings of 2015 12th International Conference on Remote Engineering and Virtual Instrumentation, REV 2015*, pp. 105. ISBN: 978-147997839-7. DOI: 10.1109/REV.2015.7087272.
13. F. Schauer, M. Krbeček, P. Beňo, M. Gerža, L. Pálka, and P. Špilakova. REMLABNET II - open remote laboratory management system for university and secondary schools research based teaching. *2015 12th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2015, art. no. 7087273, p. 109-112. ISBN 978-147997839-7. DOI: 10.1109/REV.2015.7087273.
14. Krbeček, M., Schauer, F. 2015, „Remote Experiment On Time Domain Phenomena In RLC Circuits And Their Characterization“. *TOJET: the Turkish online journal of educational technology* [online]. Turkey: TOJET, 2015, (Special 2 for INTE 2015 July,2015): 479-487. ISSN 1303-6521. Available from: [http://www.tojet.net/special/2015\\_7\\_2.pdf](http://www.tojet.net/special/2015_7_2.pdf)

15. M. Krbeček and F. Schauer. Communication and Diagnostic Interfaces in Remote Laboratory Management Systems. *International Journal of Online Engineering (iJOE)*. 2015, vol. 11, issue 5, p. 43-49. DOI: <http://dx.doi.org/10.3991/ijoe.v11i5.4926>. Available from: <http://online-journals.org/index.php/i-joe/article/view/4926/3600>
16. F. Schauer, M. Krbeček, L. Tkáč and M. Ožvoldová. Remote diagnostics of remote laboratory — On example of Joule's experiment as a probe into micro world. *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2016, pp. 242-245. DOI: 10.1109/REV.2016.7444472. ISBN 978-1-4673-8246-5. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7444472>
17. Schauer F., M. Krbeček, P. Beňo, M. Gerža, L. Pálka, and P. Špilakova. REMLABNET III — Federated remote laboratory management system for university and secondary schools. *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. IEEE, 2016, pp. 238-241. DOI: 10.1109/REV.2016.7444471. ISBN 978-1-4673-8246-5. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7444471>
18. Schauer, F.(50), M. Krbeček (40), M. Ozvoldova (5) and L. Tkac (5). INCLINE — Class of remote experiments for mechanics teaching via REMLABNET. *2015 3rd Experiment International Conference (exp.at'15)*. IEEE, 2015, pp. 291-295. DOI: 10.1109/EXPAT.2015.7463282. ISBN 978-1-4673-7717-1. Available from: <http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7463282>
19. M. Krbecek and F. Schauer, "Optimization of remote laboratories for mobile devices," *2016 International Conference on Interactive Mobile Communication, Technologies and Learning (IMCL)*, San Diego, CA, 2016, pp. 1-2. doi: 10.1109/IMCTL.2016.7753759, Available from: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7753759&isnumber=7753531>
20. V. Vesela and M. Krbecek, "Development methodologies of mobile applications," *2016 International Conference on Interactive Mobile Communication, Technologies and Learning (IMCL)*, San Diego, CA, 2016, pp. 3-4. doi: 10.1109/IMCTL.2016.7753760. Available from:

<http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7753760&isnumber=7753531>

21. Schauer, F., M. Gerža, M. Krbecek and M. Ožvoldova. “Remote Wave Laboratory” with embedded simulation – real environment for waves mastering. At: *14th International Conference on Remote Engineering and Virtual Instrumentation*. New York, USA: IEEE, 2017, p. 350-356.
22. Schauer, F., M. Gerža, M. Krbecek and P. Beňo, L. Pálka, P. Spilaková, T. Komenda, M. Ozvoldova, Z. Gerhatova, L. Tkac. REMLABNET IV – LTI federated remote laboratory management system with embedded multiparameter simulations. At: *14th International Conference on Remote Engineering and Virtual Instrumentation*. New York, USA: IEEE, 2017, p. 350-356.

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## WORK EXPERIENCE

- 06/2005–07/2005
  - **IS/IT: Systems and HW administration**
    - Honeywell Aerospace (Czech Republic)
    - Practice during the study
- 07/2011–01/2012
  - **Software developer**
    - Ing. Petr Látal, Zlín (Czech Republic)
- 01/2015–06/2015
  - **Software development project manager**
    - Business Logic s.r.o., Zlín (Czech Republic)
- 02/2012–Present
  - **Software developer, IT consultant**
    - IT Freelancer (Czech Republic)
    - Example of projects outsourcing:
      - Android application "ČP Invest" v1.0
      - Android application "CNGvitall"

## EDUCATION AND TRAINING

- 2002–2006 Graduation exam
  - Střední průmyslová škola Strojnická, Olomouc (Czech Republic)
- 2006–2009 Bc. (Information technology)
  - Thoma Baťa University in Zlín, Zlín (Czech Republic)
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  - Thoma Baťa University in Zlín, Zlín (Czech Republic)
- 09/2013–01/2014 8.01x: Physics I (Classical Mechanics) Certificate (Online course)
  - Massachusetts Institute of Technology (MITx), Massachusetts (United States)
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#### RESEARCH STAYS

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- 2015 April – Research stay at École Polytechnique Fédérale De Lausanne, Switzerland
- 2016 May – Research stay at École Polytechnique Fédérale De Lausanne, Switzerland

#### PERSONAL SKILLS

- Mother tongue
  - Czech
- Other language
  - English
- Communication skills
  - Good communication skills gained mainly by students learning and active participation at international conferences.
- Organisational / managerial skills
  - Organizational and managerial skills gained by leading of several projects both in the academic and the private business sector.
- Digital competence
  - edX Verified Certificate for Learn HTML5 from W3C
  - Professional computer skills (hardware and software), programming in Java and C/C ++, Web technologies (HTML5, CSS3, PHP, JS, Laravel, ...), Developing applications for Android operating system. Advanced skills with 2D and 3D graphics in AutoCAD, Inventor and 3D MAX.
- Other skills
  - Flexibility, reliability, performance, communication skills, pleasant demeanour, independence.

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