An Integrated Educational Platform Implementing Real, Remote Lab-Experiments for Electrical Engineering Courses

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Abstract—**This paper describes an Internet-based laboratory, named Remote Monitored and Controlled Laboratory (RMCLab) developed at University of Patras, Greece, for electrical engineering experiments. The key feature of this remote laboratory is the utilization of real experiments, in terms of instrumentation and under measurement circuits, rather than simulation or virtual reality environment. RMCLab's hardware infrastructure contains multiple reconfigurable sub-systems (FPGAs), which can be enhanced by almost any analog expansion module. The main characteristics of this system include the versatility of the hardware resources, due to the dynamic reconfiguration potentiality and the low cost of the hardware components. Moreover, this system enables its users to test, in real time, their own custom circuit designs. The paper concludes with a specific example regarding an elementary circuit in digital electronics and a short statistical review of the RMCLab educational usage. RMCLab can be accessed via the web through http://www.apel.ee.upatras.gr/rmclab.**

Index Terms — **Client-server architecture, remote laboratory, distributed instrumentation and resources**

I. Introduction

The exponential growth of computer and internet technology enables the development of complex, hybrid systems such as remote laboratories where experiments can be remotely accessed, monitored and controlled [1]-[4]. This new interpretation of the measurement process offers to anyone the opportunity to interact with the laboratory at any time, reducing at the same time the experiment cost per user and extending the capabilities of the entire experimental framework.

Paradigms of using these advanced facilities apply either for educational purposes [5]-[6] or for products' advertisement. Remote laboratories can offer high-level experimental training and experience, when they are able to realize, support and interact with real experiments, rather than present simulation results or simple depiction of reality. Additionally, expensive, often dedicated experiments, of modern, cut-edge technology can be shared worldwide, contributing thus to a high-valued remote laboratory framework.

Many internet-enabled software systems that afford distance laboratories via simulated, virtual environments can be found in the web [7]-[8]. These software systems often integrate many of the desired functionalities, especially from the user's side, such as accompaniments to the experiment documentation, communication support and collaboration among their users. Although modern simulators can accurately estimate circuits' performance, the employment and utilization of real circuits and real instrumentation, for electrical engineering laboratories [9], ensures the measurements' reliability, while at the same time increases the educative value of the remote laboratory.

Remote laboratories offering access to real lab-experiments and real instrumentation also exist, however the majority of them cannot share their resources simultaneously to many users, thus they fail to serve and support large classes of several hundreds of students.

This paper presents the specifications and the basic structure of an integrated remote laboratory platform that enables the instant remote access to real lab-experiments, employing real hardware and real instrumentation. This platform, named Remote Monitored and Controlled Laboratory (RMCLab), is able to provide high-level services to a great number of users for a wide-range of real electrical engineering experiments; either pre-configured, reconfigurable or customizable, at a very low hardware infrastructure cost. RMCLab offers its services since March 2004, at the Dept. of Electrical and Computer Engineering of University of Patras, Greece, where it was developed and implemented.

II. Proposed Approach

The basic purpose of the developed platform is to provide high-quality lab-training in electrical engineering subjects to students, all over the world. The design of such a remote laboratory for real-time, internet-based lab-experiments, should consider all aspects of the system, including communication and data flow, as well as instrumentation and hardware control [10]-[11]. RMCLab system has been designed so as to integrate all potentials of a physical laboratory to a simple user interface, among with other sub-systems, such as lab-administration, instrument operation and hardware management.

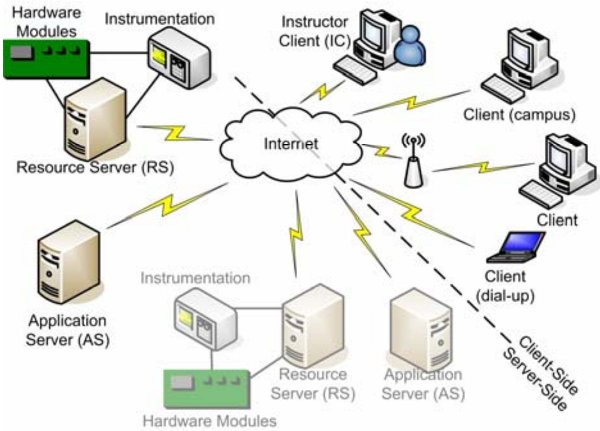

Figure. 1. RMCLab system overview.

The primary service that RMCLab platform should provide to its users is the possibility to study on the lab-experiment subjects, by accomplishing their measurements at any time and from anywhere. For this reason, RMCLab's basic specification is defined as the ability to serve at any time, simultaneously and at real time, any potential user for any available lab-experiment. On the other hand, an integrated remote laboratory platform should reinforce lab-administrator's tasks and responsibilities, regarding the experiment setup, hardware and instrumentation control, users' management and also lab-maintenance. RMCLab offers also many kinds of assessment functionalities for the students' lab-skills, regarding the lab-experiments, such as the assignment of several different evaluation criteria (measurements, instrument settings and multi-type questions, etc), so as the whole platform can be configured as an advanced tool for automated, high-level educational services, an aspect that characterizes the offered educational activities and also our initial motivation.

III. Architecture

RMCLab system has been developed based on the conventional client-server architecture, expanded in the server-side, as depicted in Fig. 1, and consists of the following basic entities: client, instructor-client (IC), application server (AS), resource server (RS) and lab-infrastructure, including the real instrumentation and all the hardware modules.

A. Network Topology

The server-side of the proposed architecture employs at least two sub-servers; the resource server and the application server. This structure could also be replicated in a more complex network topology. Resource server manages and operates hardware and instrumentation resources, providing to application server an abstract layer for communication that enables access to lab-infrastructure.

Application server undertakes the data flow control task between clients and the physical remote laboratory, realized by the resource server and the lab-instrumentation. The intermediary role of the application server is mandatory, since clients should not be to directly communicate with any of the resource servers. The communication between application server(s) and the resource server(s) or the client(s) is based on a custom, abstract language that integrates all potential tasks of a conventional, physical laboratory.

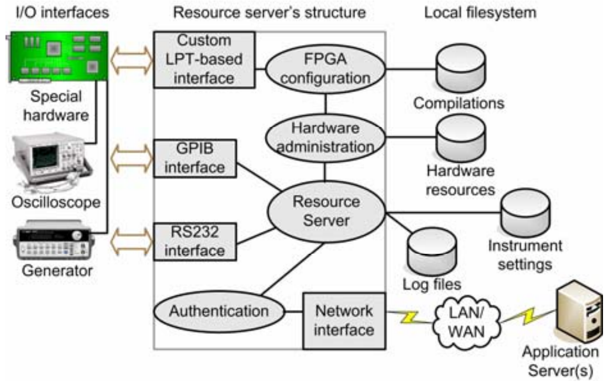

Figure. 2. Software and hardware modules of the Resource server.

This topology simplifies the architecture of the server-side and expands platform's capabilities, as it facilitates the robust development and customization of a resource server. Moreover, it enables many application servers to utilize the components shared by the resource server(s). As a result, users all over the world are able to transparently access, via the application server(s), these shared resources. Additionally, application server grants to its clients transparently access to the real resources of the physical laboratory, thus increasing system's robustness, flexibility and expandability.

B. Hardware, Instrumentation and Resource Server

The real measurement laboratory is based on a low-cost and easy implementation, while it is realized around the resource server. Resource server is equipped with suitable, interfaces toward the signals of lab-experiments (both digital and analog experiments), via a custom, LPT based bus, and the instruments, via the RS232 interface or the GPIB bus, as depicted in Fig. 2.

Multiple types (standard, programmable, pre-configured or re-configurable) of analog, digital or mixed circuits can be hosted in the platform's resource server(s). For this reason RMCLab's hardware is outfitted with a motherboard that is able to host up to 64-cards, where each of them incorporates an FPGA and extra auxiliary circuitry required for implementing the lab-circuits, as depicted in Fig. 3.

Each card employs also a PLD, which is responsible for the card addressing and the configuration of the FPGA. Each of these cards can host 8-different analog, digital or mixed independent arbitrary circuits, since the FPGA is segmented into 8-sectors, each of them corresponding to a specific lab-experiment. The internal operation of the FPGA is controlled by a register file (Table I) which is employed within it.

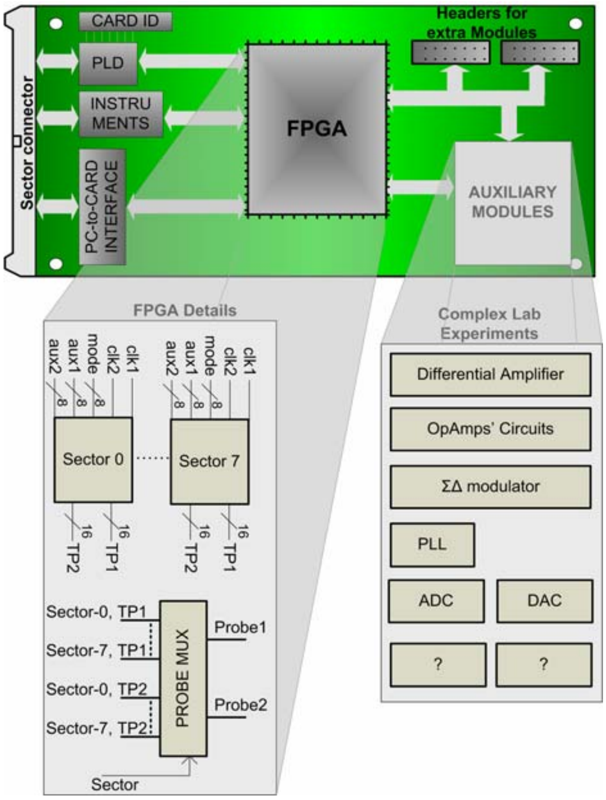

Figure. 3. Hardware architecture.

As each sector of the FPGA can host either a specific multi-mode lab-experiment or a user's custom circuit, the mode register and two auxiliary registers control its operation mode and behavior, while sector register points to the active sector, on which measurements are performed. Therefore, a single sector could implement alike lab-circuits, which can be externally presented as different lab-experiments, while the selection of the operation is performed by the value of the mode register. For example, in our case, both synchronous and asynchronous digital counters are implemented in the same sector, but are presented as two different lab-experiments. Moreover, when a measurement is carried out, two extra registers, Probe1 register and Probe2 register, assign the active nodes of the active sector, on which the two probes of the oscilloscope become physically connected through cross-point switches. Finally, each card may be offline equipped with additional on board or external circuitry, in order to implement a wide range of more complex electronic circuits, including PLL-based Frequency Synthesizers, several types of D/A or A/D Converters, ΣΔ Modulators, etc.

The aforementioned hardware architecture characteristics in combination with the network topology

TABLE I. FPGA REGISTER FILE

Name	Address	Width (bits)	Operation
Sector	0	3	Select the active sector
Probe1	1	4-6	Select the active nodes of Oscilloscope's Ch-A
Probe2	2	4-6	Select the active nodes of Oscilloscope's Ch-B
Aux1	3	8	Auxiliary register 1
Aux2	4	8	Auxiliary register 2
Mode	5	8	Sector's operation mode

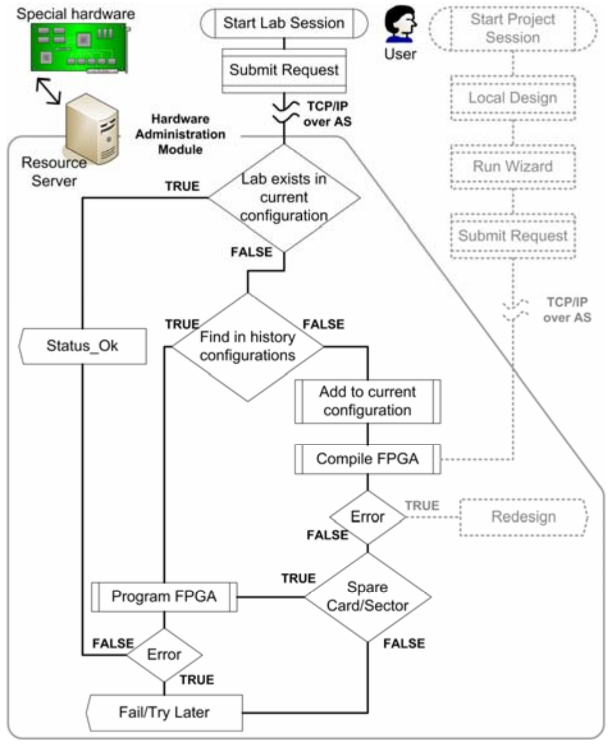

Figure. 4. Hardware administration module flowchart.

complexity necessitate an elegant and efficient management of the hardware resources and the measurement requests. A hardware administration module, depicted in Fig. 4, within the resource server, undertakes this management role. A measurement transactions starts when a client raises a measurement request, regarding either a pre-configured lab-experiment or a user's custom circuit. The later is discussed in details in Section IV. After the request is raised to the corresponding application server, by a client, is logged and forwarded, via the same application server, to the proper resource server, which supports the under-measurement circuit. Afterwards, resource server has to accomplish multiple tasks, such as the authentication of the request and the lab-infrastructure (hardware and instrumentation) setup, so as to be prepared for the requested operations. This may lead to a real-time, online re-configuration of one's card FPGA, so as to implement the requested circuit, or even to the removal of an unutilized sector's circuit, if an empty sector cannot be found. As soon as the hardware is configured, the measurement is performed and the

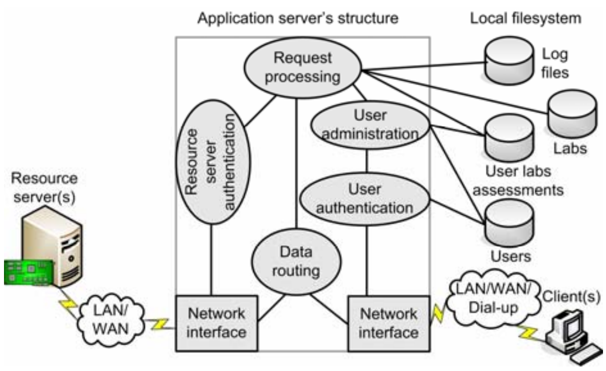

Figure. 5. Software modules of the application server.

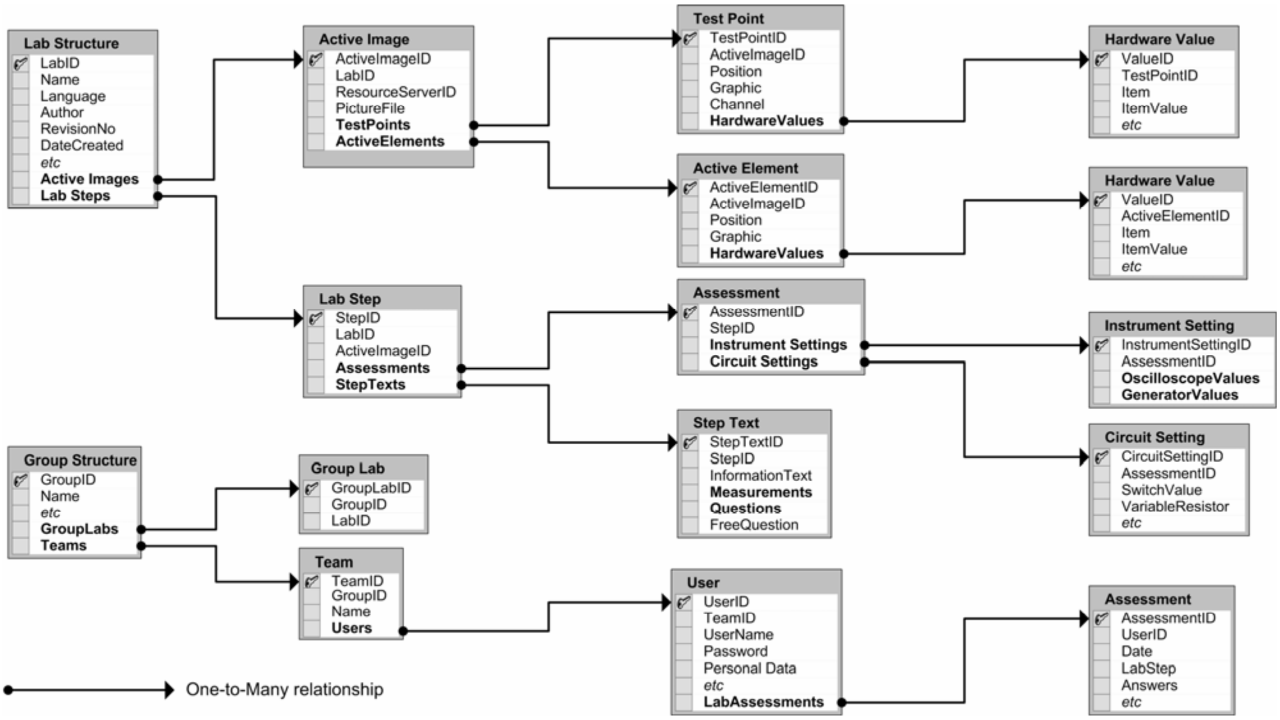

Figure. 6. Labs' and Users' data structure overview.

acquired data are transmitted back to the specific client, again via the application server. The above procedure has been designed so as to time-share the lab-infrastructure, in a FIFO priority, to all available requests.

C. Application Server

Apart from the dataflow control and the routing procedure between client(s) and the resource server(s), application server is also responsible for the authentication and logging, as well as for the assessment and evaluation of its clients' actions, when educative usage is intended. The above presented characteristics and functionalities of the application server define its architecture, as depicted in Fig. 5. Additionally, each one of the application servers of the RMCLab platform needs to be offline aware of the resource servers, that are able to communicate with, and their list of supported circuits, which are dynamically acquired upon each successful transaction with one of the resource servers.

Application server comprises also an advanced tool for the development and maintenance of a laboratory class that is available to the administrator of the laboratory, as can it be unrelated to the location of the physical laboratory, realized by the resource server, the hardware and the instrumentation. The development and maintenance of a laboratory class has been merged into a single database system, depicted in Fig. 6, which contains all the required data for the design and assignment of a lab-exercise. Additionally, the same database system includes data regarding the students. One lab-exercise may consist of several active-images, which correspond to the real lab-circuits. For each lab-circuit, test-points and active-elements (switches and variable components) can be assigned. Hardware properties required for the assignment of the test-points and the active-elements are specified in the custom abstract language, used by the RMCLab system. On the other hand, a lab-exercise is separated in several steps, where each step may contain information, regarding the theoretical and practical aspects, measurements, multiple choice questions and a free-text question. Moreover, assessment rules may be provided in each lab-step. Along with the lab-exercises' data, students' data, regarding their personal information and assessments are stored in the same database system.

The layered networking of the RMCLab system permits each laboratory administrator to present a lab-experiment, running at a specified resource server, according to his personal educational aspects, regardless of the physical location of the real hardware of the lab-experiment.

D. Client

The client-side of RMCLab's system has been designed so as to comply with the demands of a potential user. Thus, client module embeds a specific interface, named as 'scenario interface', for supporting the remote monitor and control of lab-infrastructure, and other full-functional and user friendly interfaces for lab-instrumentation (function generator, oscilloscope,

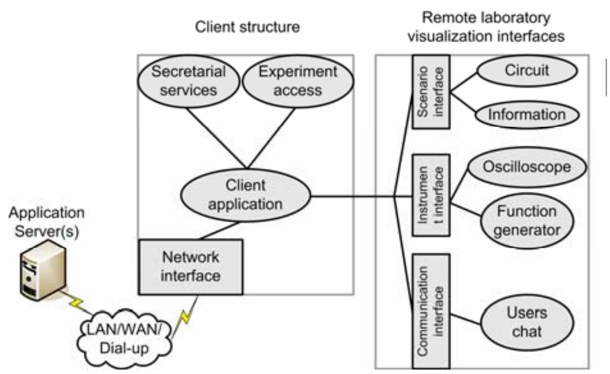

Figure. 7. Software modules of the client.

etc), as depicted in Fig. 7.

In more details, scenario interface provides a user with graphic information, related with the under study circuit. Additionally, grants to the user the control of circuit parameters (variable pots, caps, etc) and also the monitoring of any active node of the circuit, by selecting and setting the probes of the oscilloscope and the function generator on the circuit. Moreover, extra documentation, regarding the technical and theoretical aspects of the experiment, which can also be separated into multiple steps, can be presented to the user, via the scenario interface.

E. Communication Module & Instructor-Client

In order to meet the basic requirements of the collaborative interactive e-Learning, a communication interface has been incorporated into the RMCLab system. This communication interface consists of a simple chat module enabling the collaboration and the information exchange, during a remote lab-experiment. The communication interface has been integrated into the RMCLab system by request of its early users, while it is under development the expansion of the chat module with voice and video capabilities.

Finally, RMCLab's platform embeds an identical to the user's client module, named as instructor-client, which offers to a supervisor/instructor of the experiment the ability to replicate, monitor and control any online user's lab-environment. This feature is focused on the educational aspect of RMCLab platform, as it provides an instructor with the ability to closely observe and efficiently tutor the actions of any online users, concluding to a 'near-to-real' lab-environment.

F. Architecture Overview

The described hardware architecture is suitable for developing circuits of low-to-medium complexity, at a low-cost. For accessing the properties of this specific hardware, a software driver has been developed and embedded in the resource server application. Apparently, the platform is able to employ and control any hardware, under the condition that the corresponding software driver enables its access. Thus, even the use of complex or commercially available products is possible.

Additionally, the abstract language used to communicate RMCLab entities each other, can be modified according to future or different requirements. Fig. 8 depicts the dataflow diagram among the RMCLab entities and focuses on the correspondence between them.

IV. ADVANCED PROPERTIES OF THE RMCLAB

Conventional lab-education is based on the study of pre-defined lab-experiments. RMCLab system provides an outstanding benefit to its users, thus the feasibility to design and test/measure their own custom circuits under real hardware and real instrumentation. RMCLab users can offline design almost any circuit using separate software package (MAX+plus II or Quartus, both offered at no-cost for academic institutes from Altera). Using one of the aforementioned specific software packages, one can design his own circuits following a reduced set of rules and confirm by simulation its proper operation. Once the design is verified at the client-side, it can be easily uploaded to the server-side and after a while (<15 seconds) he will be able to perform any measurement on his custom design, which is now implemented on real hardware, by employing real instrumentation. The aforementioned procedure is supported by the hardware administration module of the resource server, as depicted in the dotted part of Fig. 4.

The network architecture of RMCLab platform enables the world-wide distribution of resources, in terms of lab-experiments, by utilizing multiple application servers in a single network topology, as depicted in Fig. 9. Thus, instructors all over the world can take the advantages of employing a running lab-experiment and present it in their native language and personal educational point of view. Obviously, each supervisor has the opportunity to review his users' performance by his own criteria, according to the assessments rules for each experiment, that are defined in the RMCLab's application server, which is available and accessed by the supervisor, as resource server transparently executes the measurement requests.

The prospects of the RMCLab system may hopefully expand world-wide, as the above scenario can be further extended if one adds more resource servers, as depicted

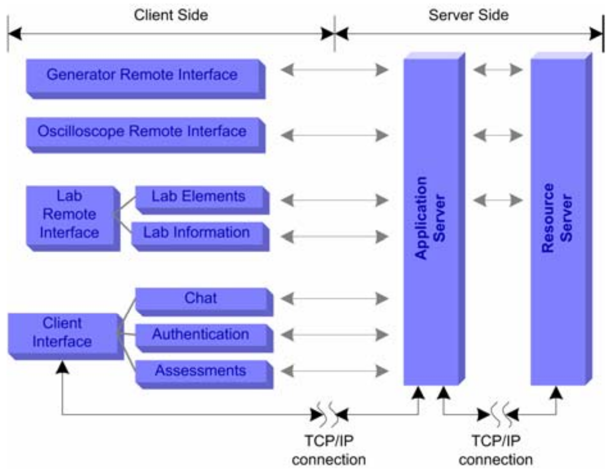

Figure. 8. RMCLab system's dataflow overview.

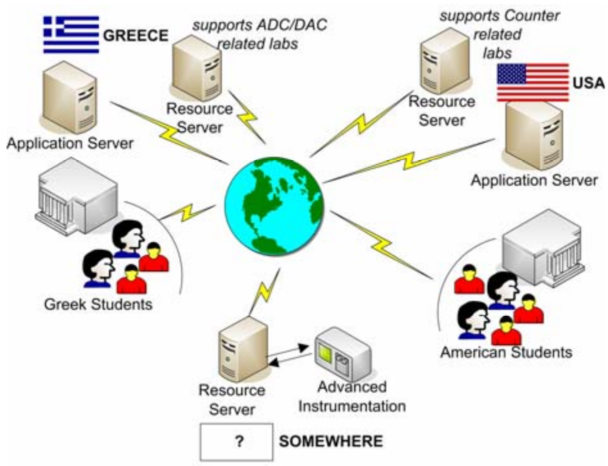

Figure. 9. Advanced RMCLab utilization.

in Fig. 9. Each resource server can be expert and focused on a specific subject, incorporating the appropriate hardware and instrumentation. Instructors all over the world may take the advantage of using such laboratory resources and develop educational material in their local application servers, in their native language, according to their own educational criteria, so as to offer advanced experimental training to their students, without any requirement for the development and maintenance of any expensive lab-infrastructure.

RMCLab's advanced utilization modes are not limited within the above example. The real-time use of real hardware and real instrumentation can significantly contribute to the educational procedure, since it enables an instructor to prepare 'Active Lessons' and present in details, during a class, the operation of a circuit or a system under real world circumstances, while at the same time can be utilized as a mean of demonstration for expensive products.

V. The Realized RMCLab System

A. Technical Characteristics

The architecture described in section III has been implemented at the University of Patras, Greece. Current configuration is a cost effective implementation, which consists of a single PC, with an Intel Hyper-Threading 2.6GHz processor and 1024MB RAM, embedding both the resource and the application server of our running RMCLab system. This PC, running Windows 2003 Server, is permanently connected to the campus LAN and also to an Agilent 54622D mixed signal oscilloscope and an Agilent 33120A function generator. Oscilloscope is connected with the PC via a high-speed GPIB interface, while function generator is controlled via RS232 @19.2kbps. The PC-interface with the hardware modules is implemented based on a custom, low-cost bus, through LPT in EPP mode. Each card of the hardware infrastructure contains an Altera FPGA of the FLEX8K series and also other components required for the implementation of the experimental circuits. The aforementioned infrastructure provides fast enough access and response (<3-secs per measurement) to the client requests, as summarized in Table II.

B. A Simple Educational Paradigm

Fig. 10 illustrates the measurement result, regarding the CLK and LOAD signals of an Early Decoding, Count Down, 4-bit Decimal Counter. The top part in Fig. 10 depicts the circuit information available to RMCLab users for the specific circuit, while the middle and bottom part depict the measurement representation of the real

TABLE II. RMCLab Time Response Characteristics.

Property	Average Delay (sec)
Hardware setup and measurement time	3
Compilation time of a custom circuit	10
Hardware re-configuration time	5
Measurement delay from client side using PSTN line @56kbps	<5

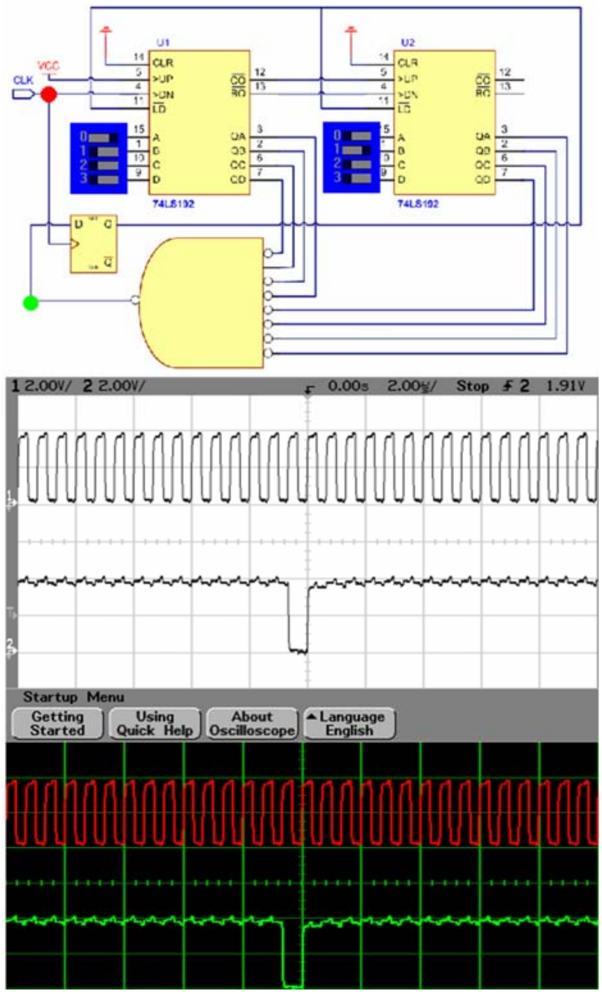

Figure. 10. Educational paradigm of RMCLab usage.

oscilloscope and the remote interface, respectively. Obviously, RMCLab system is able to take full advantages of the real hardware and real instrumentation utilization, providing measurements, regarding a wide variety of signals' properties, and the full control of both instruments (oscilloscope and function generator).

C. Educational Utilization

RMCLab system provides its educational services since March 2004 to the Dept. of Electrical and Computer Engineering of University of Patras, Greece, supporting classes of approximately 300-students, in two core lessons, regarding Analog and Digital Electronics. Analog lab-experiments include 2-stage feedback amplifiers and cascade/folded-cascade amplifiers, whereas digital experiments include a wide variety of topologies regarding counters, adders and accumulators.

A class of the Dept. of Electrical and Computer Engineering of our University has about 300-students. Students are grouped in teams of 3-to-4 persons per team, in order to perform 6-obligatory lab-experiments per semester. For convenience, the same grouping was retained for accessing RMCLab services. Thus, for the second semester of academic year 2004-'05, RMCLab has to offer its services to 80-teams, for 2-obligatory lab-experiments. Five more obligatory lab-experiments were also carried out in the conventional way. The two

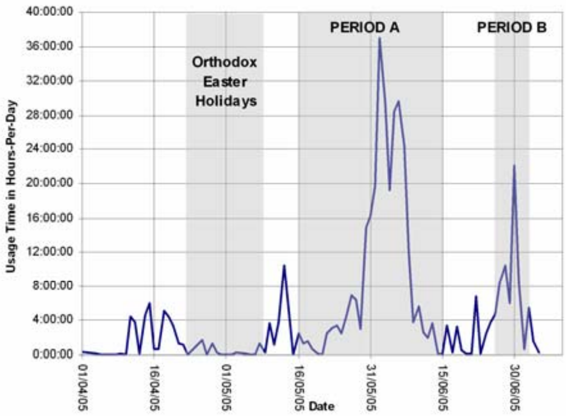

Figure. 11. RMCLab's cumulative utilization during the second semester of academic year 2004-'05.

RMCLab-based experiments referred to binary/decimal synchronous counters and special purpose programmable up/down counters, using the 74192 chip.

Students' obligations regarding the RMCLab-based experiments were announced the second week of April '05. Fig. 11 depicts the RMCLab's cumulative utilization, considering that students had to carry out these experiments in PERIOD A, while the re-examination took place in PERIOD B.

During the aforementioned period, RMCLab has been extensively employed for its services; thus 17200 measurements were logged on the platform's instrumentation, where 1666 of them regarded an introductory exercise, and 4458, 11076 measurements regarded the first and the second obligatory exercise, respectively. For the first obligatory exercise the performed measurements were 4.35-times more than the total number required for completing the exercise by an expert, while for the second one this ratio was reduced to 3.97, despite the fact that this exercise was significantly more demanding for the students. This implies that students easily acquired experience on the use of the RMCLab platform.

During the same period, up-to 8-simultaneous requests have been raised to the RMCLab resource server, without importing any extra delay to the users' requests servicing. The 74-active teams fulfilled their lab obligations in 383h 30m 20s, thus, approximately 2.6-hours per lab-experiment. Fig. 12 and Fig. 13 depict the cumulative

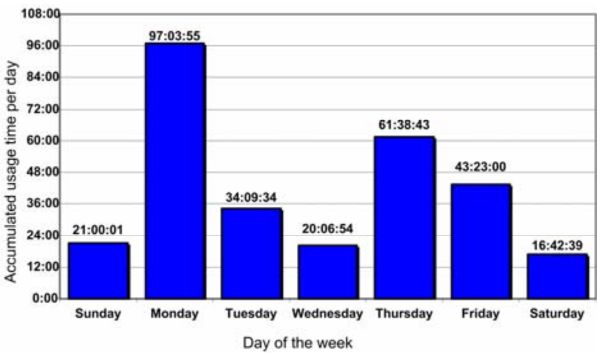

Figure. 12. RMCLab's cumulative usage time vs. day of the week for the second semester of academic year 2004-'05.

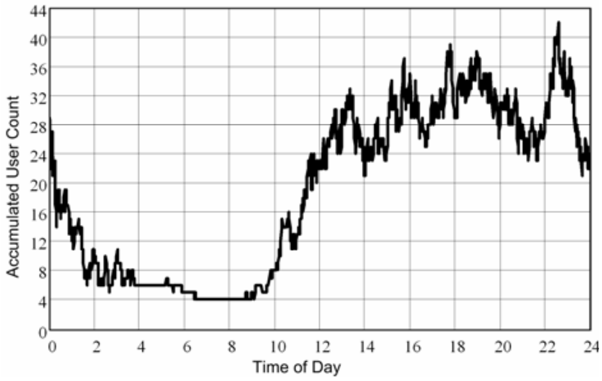

Figure. 13. RMCLab's cumulative user count vs. time of the day for during the second semester of academic year 2004-'05.

user count and the cumulative usage time of the RMCLab services versus the time of the day and the day of the week, respectively, for the aforementioned period. Apparently, services like RMCLab enable students to take over their obligations in a reasonable time while exploiting efficiently their wide spread working hours. Additionally, RMCLab platform carried out extensively and fair the assessments of the students' performance, regarding their lab skills, thus providing a valuable service for the instructor.

VI. CONCLUSION

RMCLab platform is able to provide a wide range of high educational services in a great number of students. It increases the productivity of the students by enabling them to have access to the lab-infrastructure at non-working hours, while at the same time affects significantly their psychological mood regarding the level of the offered education by their institute.

Moreover, RMCLab accomplishes its services employing a single PC and a single set of hardware and instrumentation, thus pointing out that is able to provide high-quality lab-education at low-cost, without time-consuming human insteraction.

The structure of RMCLab enables sharing of hardware and instrumentation resources, thus makes possible the extensive exploitation of an expensive lab-infrastructure, facilitating the wide spread of remote real lab-experiments, which are indisputably valuable for engineers' education. Additionally, hardware re-configurability permits the remote implementation and measurement of electronic circuits, providing further more a high-valued educational service.

The concentrated use of RMCLab system during 6-academical semesters, for the courses of Analog and Digital Integrated Circuits, consisting of classes of about 300-students per class, has definitely proved the high value of this educational tool, for the students and for the instructors as well.

It is anticipated that the proposed architecture guidelines along with the success of the RMCLab platform will motivate educational community to cooperate, so as to develop an integrated World-Wide-Lab environment.

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A WEB-BASED, DISTRIBUTED, REAL EDUCATIONAL LABORATORY FOR ELECTRICAL ENGINEERING COURSES

E. Kostas* and K. Dimitris*

Abstract

This paper presents an Internet-based laboratory, named as Remote Monitored and Controlled Laboratory (RMCLab), aiming to provide high-quality lab training in electrical engineering subjects to students all over the world. The key feature of this remote laboratory is the utilization of real experiments, by employing real instrumentation and real circuits, rather than simulation or virtual reality environment. RMCLab's hardware infrastructure contains multiple reconfigurable sub-systems (FPGAs), which can be enhanced by many analog expansion modules. The main characteristics of this system include the versatility of the hardware resources, due to the dynamic reconfiguration potentiality, as well as the low cost of the hardware components. Moreover, this system enables its users to test, in real time, their own custom circuit designs. This paper provides information regarding the architecture of RMCLab and concludes with a specific example regarding the implementation of an elementary circuit in digital electronics and a short statistical review of the RMCLab educational usage.

Key Words

Client–server architecture, remote laboratory, distributed instrumentation and resources

1. Introduction

The exponential growth of computer and Internet technology enables the development of complex and hybrid systems, in terms of software and hardware composition, such as remote laboratories where experiments can be remotely accessed, monitored and controlled [1]. This new interpretation of the measurement process offers to anyone the opportunity to interact with the laboratory at any time, at the same time reducing the cost of experiments per user, while the use of modern technology extends the capabilities of the entire experimental framework.

Paradigms of using these advanced facilities apply either for educational purposes [2] or for products' advertisement. Remote laboratories can offer high-level experimental training and experience, provided that they are able to realize, support and interact with real experiments, rather than present simulation results or simple depiction of reality. Additionally, expensive, often dedicated experiments, of modern, cut-edge technology can be shared worldwide, contributing thus to a high-valued remote laboratory framework.

Many Internet-enabled software systems that employ distance laboratories via simulated, virtual environments can be found in the web [3]. These software systems often integrate many of the desired functionalities, especially from the user's side, such as accompaniments to the experiment documentation, communication support and collaboration among their users. Although modern simulators can accurately estimate circuits' performance, the employment and utilization of real circuits and real instrumentation, for electrical engineering laboratories [4], ensures the measurements' reliability, while at the same time increases the educational value of the remote laboratory and affects positively the psychological mood of the user.

Remote laboratories offering access to real lab experiments and real instrumentation also exist, however the majority of them cannot share their resources simultaneously to many users, thus they fail to serve and support large classes of several hundreds of students.

This paper presents the specifications and the basic structure of an integrated remote laboratory platform that enables the instant remote access to real lab experiments, employing real hardware and real instrumentation [5]. This platform, named Remote Monitored and Controlled Laboratory (RMCLab), is able to provide high-level services to a large number of users for a wide-range of real electrical engineering specific experiments. These experiments can be pre-configured, reconfigurable or customizable, at a very low hardware infrastructure cost.

2. Proposed Approach

The basic purpose of the developed platform is to provide high-quality lab training in electrical engineering subjects to students all over the world. The design of such a remote laboratory for real-time, Internet-based lab experiments, should consider all aspects of the system, including communication and data flow, as well as instrumentation and

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hardware control [6]. RMCLab has been designed so as to integrate all the capabilities of a physical laboratory to a simple but efficient user interface, along with other sub-systems, that perform lab administration, instrument operation and hardware management.

The primary service that RMCLab should provide to its users is the capability to study on the lab experiment subjects, by affordably accomplishing measurements at any time and from anywhere. For this reason, RMCLab's basic specification is defined as the ability to serve at any time, simultaneously and at real time, any potential user for any available lab experiment. On the other hand, an integrated remote laboratory platform should reinforce the lab administrator's tasks and responsibilities, regarding the experiment setup, hardware and instrumentation control, users' management and also lab maintenance. RMCLab offers also many kinds of assessment functionalities for the students' lab skills, regarding the lab experiments, such as the assignment of several different evaluation criteria (measurements, instrument settings and multi-type questions, etc.), so as the whole platform can be configured as an advanced tool for automated, high-level educational services, an aspect that characterizes the offered educational activities and also our initial motivation.

3. Architecture

RMCLab has been developed based on the conventional client–server architecture, expanded in the server-side, as depicted in Fig. 1. It consists of the following basic entities: client, instructor-client (IC), application server (AS), resource server (RS) and lab infrastructure, which includes the real instrumentation and all the hardware modules.

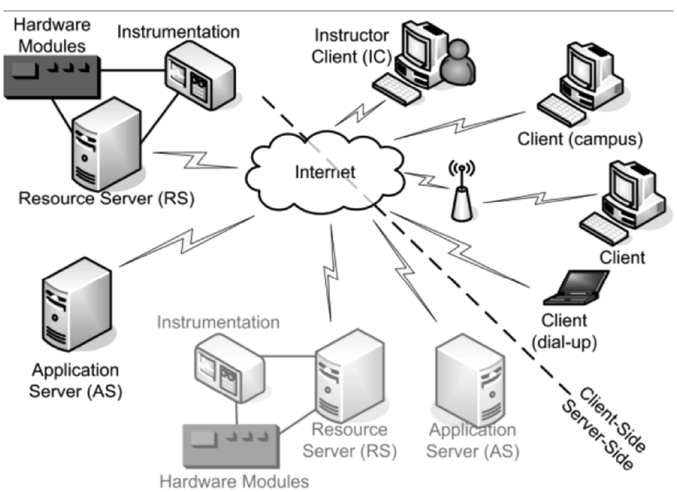

Figure 1. RMCLab system overview.

3.1 Network Topology

The server-side of the proposed architecture employs at least two sub-servers: the resource server and the application server. This structure could also be replicated in a more complex network topology. The resource server manages and operates hardware and instrumentation resources, providing to the application server an abstract layer for communication that enables access to the lab infrastructure.

The application server undertakes the data flow control task between clients and the physical remote laboratory, which consists of the resource server and the lab instrumentation. The intermediary role of the application server is mandatory, as system abstraction dictates that clients should not directly communicate with any of the resource servers. The communication between the application server(s) and the resource server(s) or the client(s) is based on a custom, abstract language that integrates all potential tasks of a conventional, physical laboratory.

This topology simplifies the architecture of the server side and expands the platform's capabilities, as it facilitates the robust development and customization of the resource server. Moreover, it enables many application servers to utilize the physical resources (such as lab instrumentation and lab circuits) shared by the resource server(s). As a result, users all over the world are able to transparently access these shared resources via the application server(s). Additionally, the application server grants to its clients transparent access to the real resources of the physical laboratory, thus increasing system's robustness, flexibility and expandability.

3.2 Hardware, Instrumentation and Resource Server

The measurement laboratory is based on low cost and low complexity hardware, while it is realized around the resource server. The resource server is equipped with suitable interfaces for the signals of lab experiments (both digital and analog experiments), via a custom LPT-based bus, and the instruments, via the RS232 interface or the General Purpose Interface Bus (GPIB), as depicted in Fig. 2.

Multiple types (standard, programmable, preconfigured or reconfigurable) of analog, digital or mixed circuits can be hosted on the platform's resource server(s). For this reason, RMCLab's hardware is outfitted with a motherboard that is able to host up to 64 cards, where each of them incorporates an FPGA and extra auxiliary circuitry required for implementing the lab circuits, as depicted in Fig. 3.

Each card employs also a PLD, which undertakes card addressing and FPGA configuration. Each of these cards can host eight different analog, digital or mixed (analog and digital) independent arbitrary circuits; as the FPGA is segmented into eight sectors, each of them corresponding to a specific lab experiment. The number of sectors or circuits that a single FPGA can host has been selected taking into account the average complexity of electrical engineering lab experiments and the spare slots of the FPGA. The internal operation of the FPGA is controlled by a register file (Table 1) which is employed within it.

Each sector of the FPGA can host either a specific multi-mode lab experiment or a user's custom circuit. The

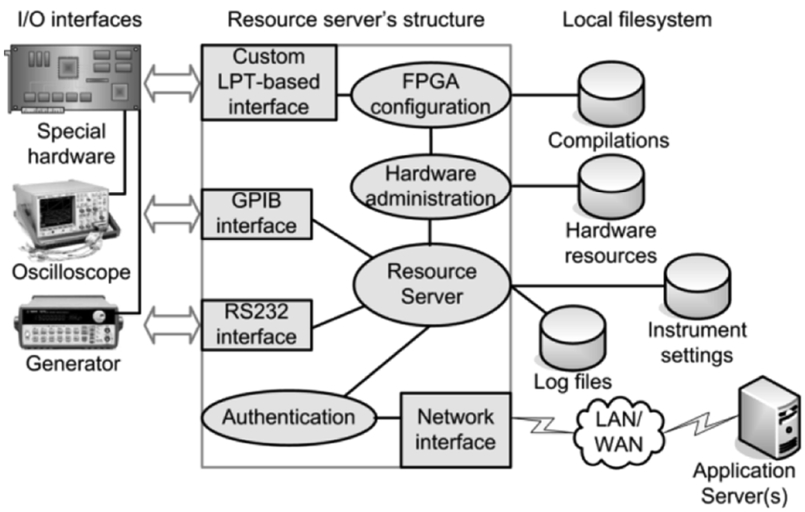

Figure 2. Software and hardware modules of the resource server.

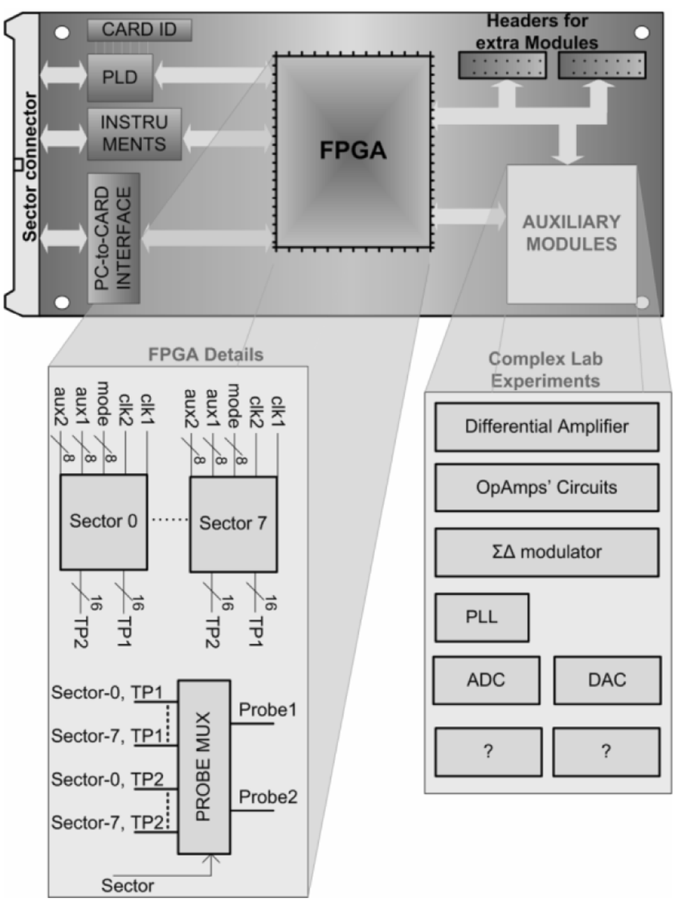

Figure 3. Hardware architecture.

Table 1
FPGA Register File

Name	Address	Width (Bits)	Operation
Sector	0	3	Select the active sector
Probe1	1	4–6	Select the active nodes of oscilloscope's Ch-A
Probe2	2	4–6	Select the active nodes of oscilloscope's Ch-B
Aux1	3	8	Auxiliary register 1
Aux2	4	8	Auxiliary register 2
Mode	5	8	Sector's operation mode

mode register controls the operation mode of a multi-mode lab experiment (e.g., a counter can be either decimal or binary) and the two auxiliary registers allow the user to control the behaviour of lab experiment (e.g., allows the user to assign the modulo of a programmable counter). Finally, the sector register points to the active sector, on which measurements are performed. Therefore, a single sector could implement alike lab circuits, which can be externally presented as different lab experiments, while the selection of the operation is performed by the value of the mode register. For example, in our case, both synchronous and asynchronous digital counters are implemented in the same sector, but they are presented as two different lab experiments. Moreover, when a measurement is carried out, two extra registers, registers Probe1 and Probe2, assign the active nodes of the active sector on which the two probes of the oscilloscope become physically connected through cross point switches. Finally, each card may be offline equipped with additional on board or external circuitry to implement a wide range of more complex electronic circuits, including several types of PLL-based Frequency Synthesizers, several types of D/A or A/D Converters, ΣΔ Modulators, etc.

The aforementioned hardware architecture characteristics in combination with the network topology complexity necessitate an elegant and efficient management of the hardware resources and the measurement requests. A hardware administration module, depicted in Fig. 4, within the resource server, undertakes this management role. A

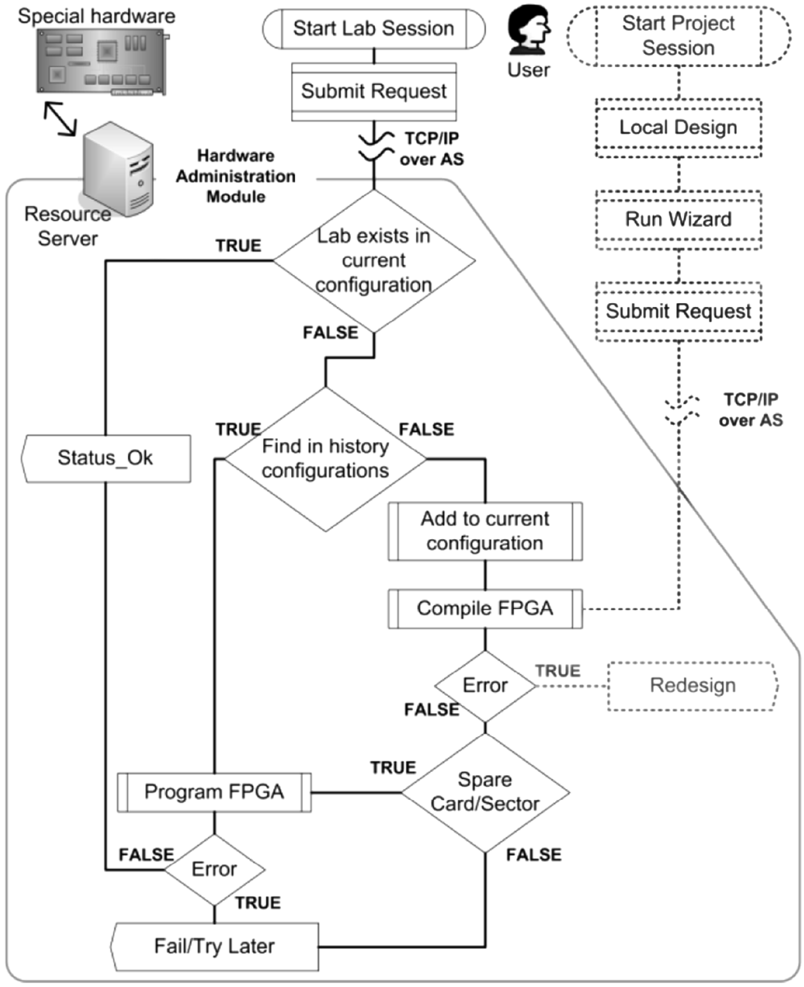

Figure 4. Hardware administration module flowchart.

measurement transaction starts when a client raises a measurement request regarding either a preconfigured lab experiment or a user's custom circuit. The later is discussed in detail in Section 4. After the request is raised by a client to the corresponding application server, it is logged and forwarded via the same application server to the proper resource server which supports the under measurement circuit. Afterwards, the resource server has to accomplish multiple tasks, such as the authentication of the request and the lab infrastructure (hardware and instrumentation) setup, so as to be prepared for the requested operations. This may lead to a real-time, online reconfiguration of the FPGA in a card, so as to implement the requested circuit, or even to the removal of an unutilized sector's circuit, if an empty sector cannot be found. As soon as the hardware is configured, the measurement is performed and the acquired data are transmitted back to the specific client, again via the application server. The above procedure has been designed so as to time-share the lab infrastructure, in a FIFO priority, to all available requests.

3.3 Application Server

Apart from the dataflow control and the routing procedure between the client(s) and the resource server(s), the application server is also responsible for the authentication and logging, as well as for the assessment and evaluation of its clients' actions, when educational usage is intended. The above presented characteristics and functionalities of the application server define its architecture, as depicted in Fig. 5. Additionally, each one of the application servers of RMCLab needs to be offline aware of the resource servers, that is able to communicate with, and their list of supported circuits, which are dynamically acquired upon each successful transaction with one of the resource servers.

The application server constitutes also an advanced tool for the development and maintenance of a laboratory class that is available to the administrator of the laboratory, as it can be unrelated to the location of the physical laboratory, realized by the resource server, the hardware and the instrumentation. The development and maintenance of a laboratory class has been merged into a single database system, as depicted in Fig. 6, which contains all the required data for the design and assignment of a lab exercise. Additionally, the same database system includes data regarding the students. One lab exercise may consist of several active images, which correspond to the real lab circuits. For each lab circuit, test-points and active elements (switches and variable components) can be assigned. Hardware properties required for the assignment

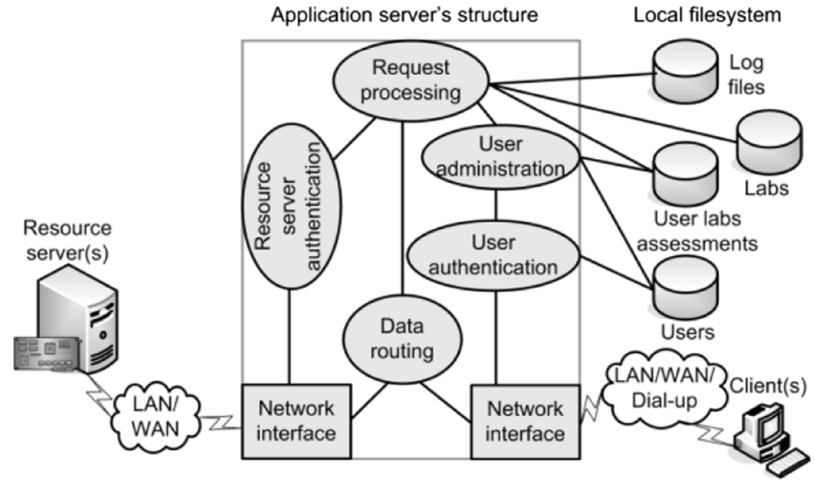

Figure 5. Software modules of the application server.

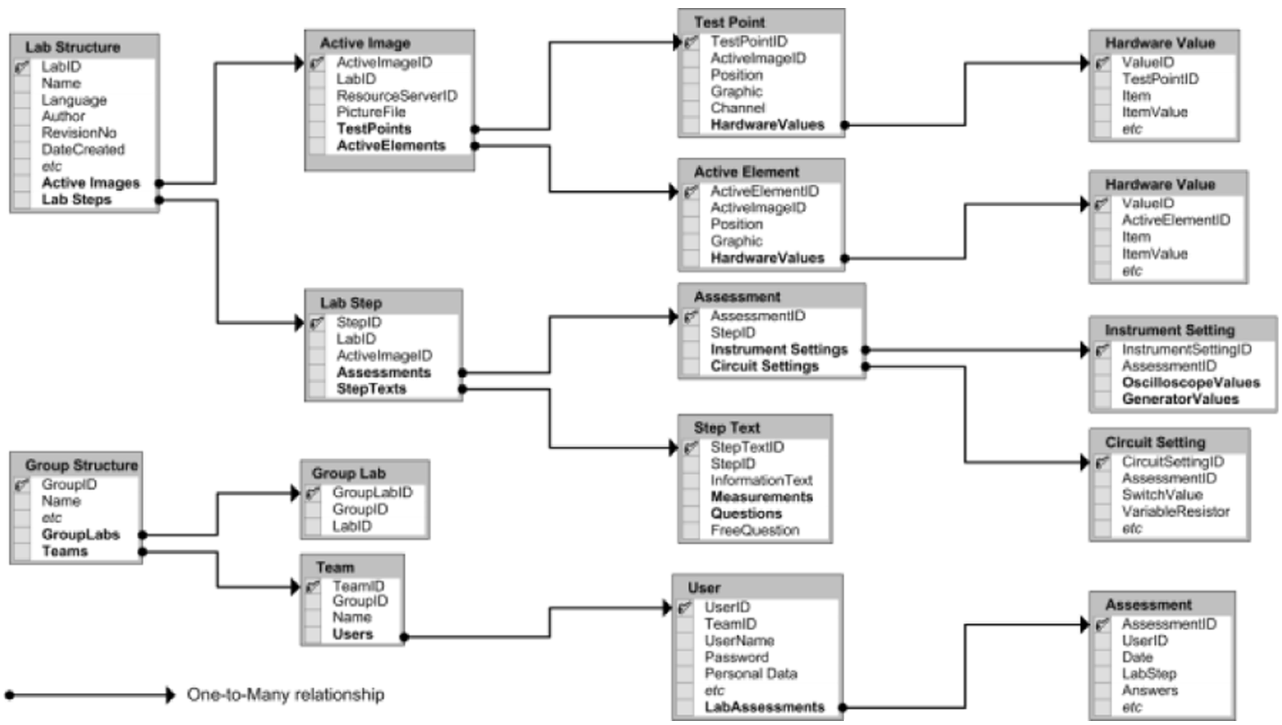

Figure 6. Labs' and users' data structure overview.

of the test-points and the active elements are specified in the custom abstract language, used by the RMCLab. On the other hand, a lab exercise is divided into several steps, where each step may contain information, regarding the theoretical and practical aspects, requests for measurements, multiple choice questions and a free-text question. Moreover, the assessment rules may be provided in each step of a specific lab. Along with the lab experiment's data, students' data regarding their personal information and their assessment are stored in the same database system.

The layered networking of RMCLab permits each laboratory administrator to present a lab experiment, running at a specified resource server, according to his personal educational aspects, regardless of the physical location of the hardware of the lab experiment.

3.4 Client

The client-side of RMCLab has been designed so as to comply with the demands of a potential user. Thus, the client module embeds a specific interface, named "scenario interface", for supporting the remote monitor and control of lab infrastructure, and other full functional and user friendly interfaces for lab instrumentation (function generator, oscilloscope, etc.), as depicted in Fig. 7.

In more detail, the scenario interface provides a user with graphic information, related to the under study circuit. Additionally, the interface grants to the user the control of circuit parameters (variable pots, caps, etc.) and also the monitoring of any active node of the circuit, by selecting and setting the probes of the oscilloscope and the

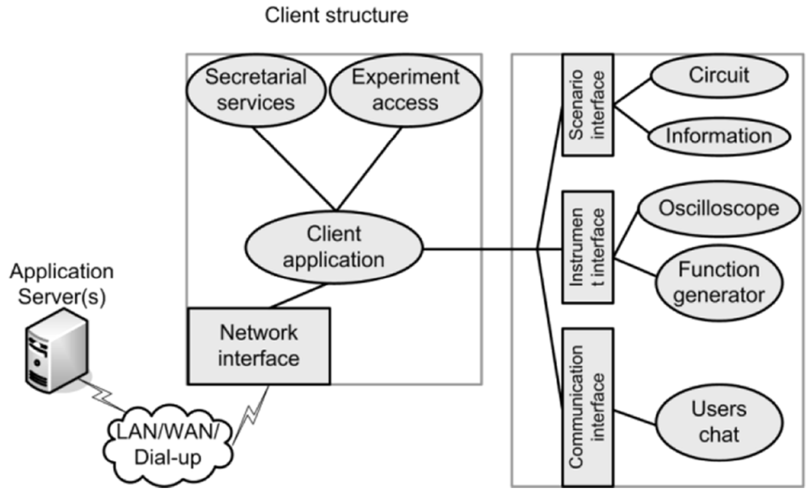

Figure 7. Software modules of the client.

function generator on the circuit. Moreover, extra documentation, regarding the technical and theoretical aspects of the experiment, which can also be separated into multiple steps, can be presented to the user, via the scenario interface.

3.5 Communication Module and Instructor Client

To meet the basic requirements of the collaborative interactive e-Learning, a communication interface has been incorporated into the RMCLab. This communication interface consists of a simple chat module enabling the collaboration and the information exchange during a remote lab experiment. The communication interface has been integrated into RMCLab by request of its early users, while the expansion of the chat module with voice and video capabilities is under development.

Finally, RMCLab platform embeds an identical to the user's client module, named the instructor-client. This module offers to a supervisor/instructor of the experiment the ability to replicate, monitor and control any online user's lab environment. This feature is focused on the educational aspect of RMCLab, as it provides an instructor with the ability to closely observe and efficiently tutor the actions of any online users.

3.6 Architecture Overview

The described hardware architecture is suitable for developing circuits of low to medium complexity, at a low cost. For accessing the properties of this specific hardware, a software driver has been developed and embedded in the resource server application. Apparently, the platform is able to employ and control any hardware, under the condition that the corresponding software driver enables its access. Thus, even the use of complex or commercially available products is possible.

Additionally, the abstract language used by RMCLab entities to communicate with each other can be modified according to future or different requirements. Fig. 8 depicts the dataflow diagram among the RMCLab entities and focuses on the correspondence between them.

4. Advanced Properties of the RMCLab

Conventional lab education is based on the study of predefined lab experiments. RMCLab provides an outstanding benefit to its users, i.e., the feasibility to design and test/measure their own custom circuits under real hardware and real instrumentation. RMCLab users can offline design almost any circuit using a separate software package (MAX+plus II or Quartus, both offered at no-cost for academic institutes from Altera [7]). Using one of the aforementioned specific software packages, one can design his own circuits following a reduced set of rules and confirm by simulation its proper operation. Once the design is verified at the client-side, it can be easily uploaded to the server-side and after a while (<15 s) the user will be able to perform any measurement on his custom design, which is now implemented on real hardware, by employing real instrumentation. The aforementioned procedure is supported by the hardware administration module of the resource server, as depicted in the dotted part of Fig. 4.

The network architecture of RMCLab enables the world-wide distribution of resources, in terms of lab experiments, by utilizing multiple application servers in a single network topology, as depicted in Fig. 9. Thus, instructors all over the world can take the advantages of employing an existing lab experiment and present it in their native language and personal educational point of view. Obviously, each supervisor has the opportunity to review his users' performance by his own criteria, according to the assessments rules for each experiment, that are defined in the RMCLab's application server, which is available and accessed by the supervisor, as the resource server transparently executes the measurement requests.

The prospects of the RMCLab may hopefully expand world-wide, as the above scenario can be further extended

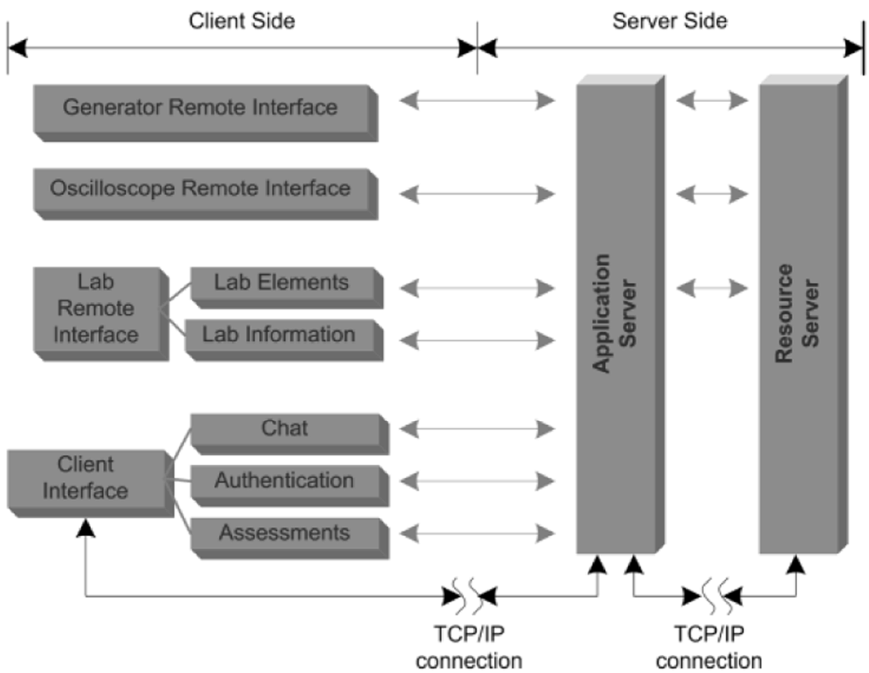

Figure 8. RMCLab's dataflow overview.

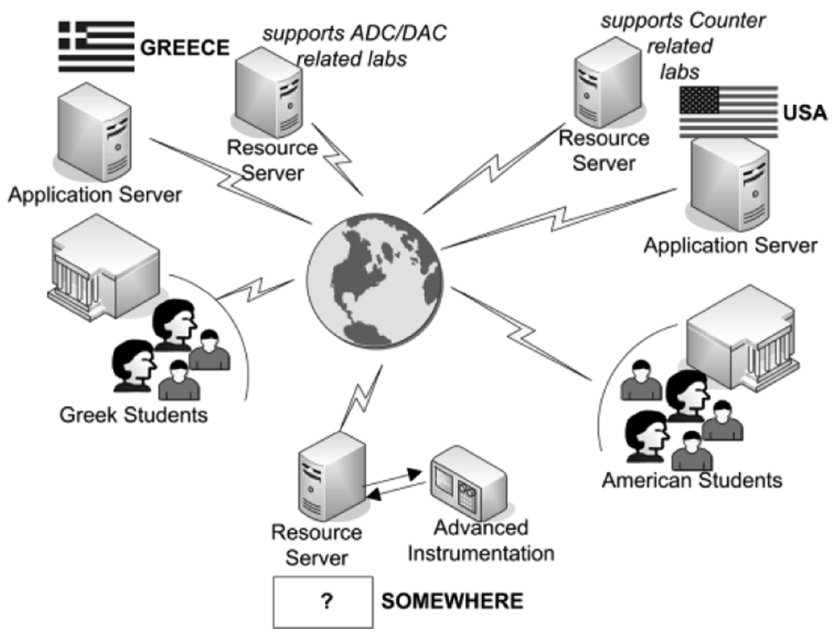

Figure 9. Advanced RMCLab utilization.

if one adds more resource servers, as depicted in Fig. 9. Each resource server can be focused on a specific subject, incorporating the appropriate hardware and instrumentation. Instructors all over the world may take the advantage of using such laboratory resources and develop educational material in their local application servers, in their native language, according to their own educational criteria, so as to offer advanced experimental training to their students, without any requirement for the development and maintenance of any expensive lab infrastructure.

RMCLab's advanced utilization modes are not limited within the above example. The real-time use of real hardware and real instrumentation can significantly contribute to the educational procedure, because it enables an instructor to prepare "Active Lessons" and present in detail, during a class, the operation of a circuit or a system under real world circumstances, while at the same time it can be utilized as a means of demonstration for expensive products.

5. The Realized RMCLab System

The architecture described in Section 3 has been implemented at the University of Patras, Greece. The current configuration is a cost effective implementation, consisting of a single PC, with an Intel Hyper-Threading 2.6 GHz processor and 1024 MB RAM, embedding both the resource and the application server of our running RMCLab. This PC, running Windows 2003 Server, is permanently connected to the campus LAN and also to an Agilent 54622D mixed signal oscilloscope and an Agilent 33120A function generator. The oscilloscope is connected with the PC via a high-speed GPIB interface, while the function generator is controlled via RS232 at 19.2 kbps. The PC interface with the hardware modules is implemented based on a custom, low-cost bus, through LPT in EPP mode. Each card of the hardware infrastructure contains an Altera FPGA of the FLEX8K series and also other components required for the implementation of the experimental circuits. The aforementioned infrastructure provides fast enough access and response (<3 s per measurement) to the client requests, as summarized in Table 2.

Table 2
RMCLab's Time Response Characteristics

Property	Average Delay (s)
Hardware setup and measurement time	3
Compilation time of a custom circuit	10
Hardware reconfiguration time	5
Measurement delay from client side using PSTN line at 56 kbps	<5

5.1 A Simple Educational Paradigm

Fig. 10 illustrates how a lab circuit is presented to students via RMCLab and also the information that is available to the students for the specific circuit. The specific lab circuit regards an Early Decoding, Count Down, 4-bit Decimal Programmable Counter. It should be mentioned that actually this circuit does not contain only a static image, but some "active elements", such as the test-points and two switches, as depicted in Fig. 10. The student is able to interact with these active elements, e.g., he could change the value of the switches or select a different test-point to measure.

Fig. 11 depicts the result of the measurement, as presented in RMCLab, regarding the CLK and LOAD signals of the 4-bit counter, while Fig. 12 depicts the same measurement if acquired directly from the oscilloscope. Obviously, RMCLab is able to take full advantage of the real hardware and real instrumentation utilization, providing measurements, regarding a wide variety of signals' properties, and the full control of both instruments (oscilloscope and function generator).

Figure 11. The measurement result presented in the RMCLab's remote interface.

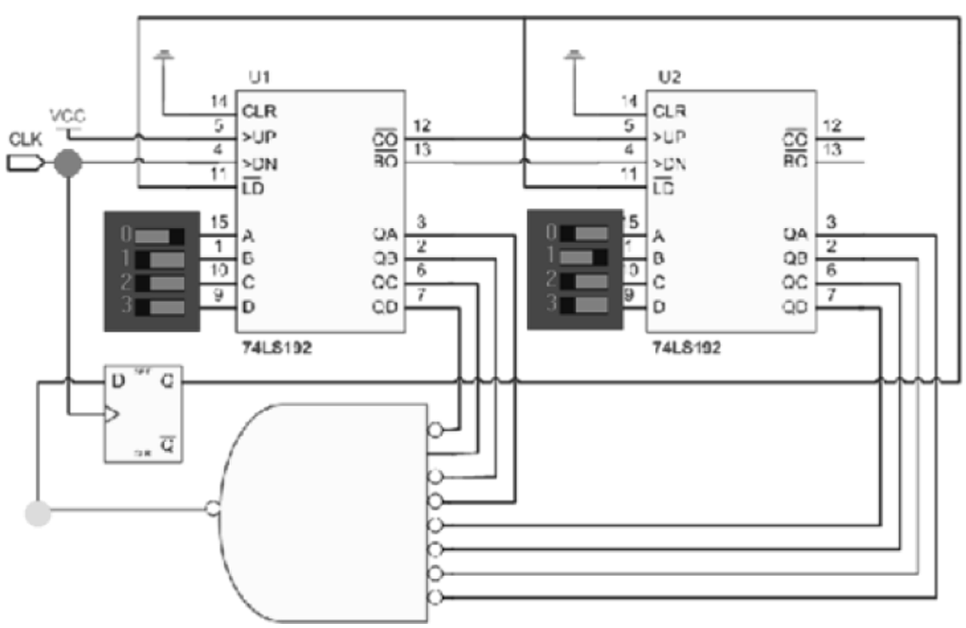

Figure 10. The lab circuit presented via RMCLab, for an Early Decoding, Count Down, 4-bit Decimal Counter.

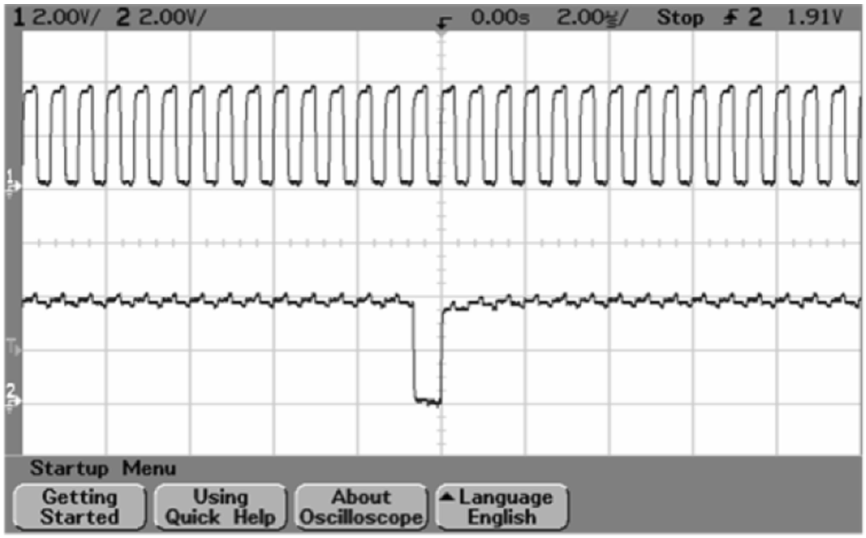

Figure 12. The measurement result acquired directly from the oscilloscope.

Figure 13. RMCLab's cumulative users count versus time of the day for the first and second semester of 2006–07.

Figure 14. RMCLab's cumulative usage count versus day of the week for the first and second semester of 2006–07.

5.2 Educational Utilization

RMCLab provides its educational services since March 2004 to the Department of Electrical and Computer Engineering of University of Patras, Greece, supporting large classes, in two core lessons, regarding Analog and Digital Electronics. Analog lab experiments include two-stage feedback amplifiers and cascade/folded-cascade amplifiers, whereas digital experiments include a wide variety of topologies regarding counters, adders and accumulators.

Figs. 13 and 14 depict the cumulative user count versus time of the day and the cumulative usage time versus day of week for a single RMCLab-based lab experiment that students had to carry out during the first and second semester of 2006–07 for the lesson Analog and Digital Integrated Circuits, respectively. It is noticeable that RMCLab server has logged 6022 oscillographs and 495 total accesses for the lab experiment of the first semester for all the active teams participated in this lab while 6404 oscillographs and 336 total accesses have been logged for the lab experiment of the second semester, despite the fact that this exercise was significantly more demanding for the students. This implies that students easily acquired experience on the use of the RMCLab platform.

6. Conclusion

RMCLab is able to provide a wide range of high educational services to a great number of students. It increases the productivity of the students by enabling them to have access to the lab infrastructure at non-working hours, while at the same time affects significantly their psychological mood regarding the level of the offered education by their institute.

Moreover, RMCLab accomplishes its services employing a single PC and a single set of hardware and instrumentation, thus pointing out that is able to provide high-quality lab education at low cost, without time consuming human interaction. The structure of RMCLab enables the sharing of hardware and instrumentation resources, thus making possible the extensive exploitation of an expensive lab infrastructure, facilitating the wide spread of remote real lab experiments, which are indisputably valuable for engineers' education. Additionally, hardware reconfigurability permits the remote implementation and measurement of electronic circuits, providing furthermore a high-valued educational service. Finally, services like RMCLab enable students to fulfil their obligations in a reasonable time while exploiting efficiently their widespread working hours.

It is anticipated that the proposed architecture guidelines along with the success of the RMCLab platform will motivate the educational community to cooperate so as to develop an integrated World Wide Lab environment.

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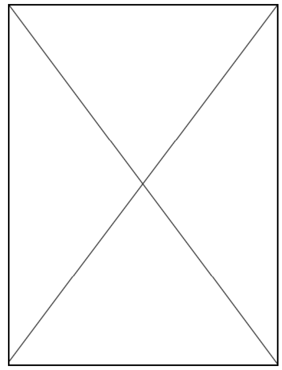

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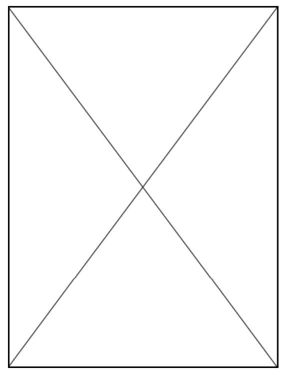

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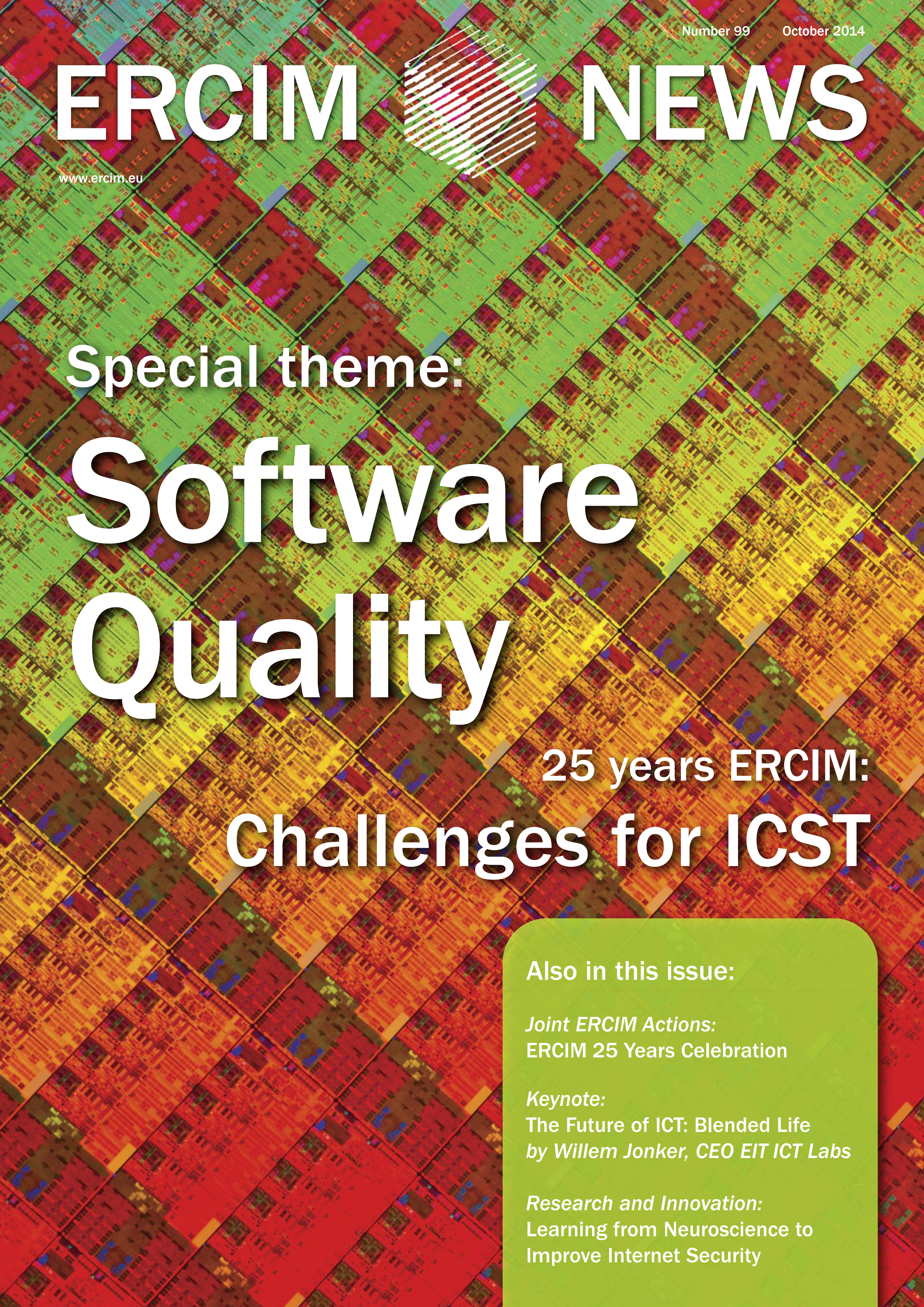

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comes gained from the relocation rules currently being deployed by most ambulance providers. Currently we are in the field trial phase and are setting up a number of newly developed DAM algorithms, in collaboration with a number of ASPs in the Netherlands. These activities are part of the project 'From Reactive to Proactive Planning of Ambulance Services', partly funded by the Dutch agency Stichting Technologie & Wetenschap.

Links:
http://repro.project.cwi.nl
Dutch movie: http://www.wetenschap24.nl/programmas/de-kennis-van-nu-tv/onderwerpen/2014/april/wiskunde-redt-mensenlevens.html

References:
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[2] C.J. Jagtenberg, S. Bhulai, R.D. van der Mei: "A polynomial-time method for real-time ambulance redeployment", submitted.
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An IoT-based Information System Framework towards Organization Agnostic Logistics: The Library Case

by John Gialelis and Dimitrios Karadimas

SELIDA, a printed materials management system that uses radio frequency identification (RFID), complies with the Web-of-Things concept. It does this by employing object naming based services that are able to provide targeted information regarding RFID-enabled physical objects that are handled in an organization agnostic collaborative environment.

Radio Frequency Identification (RFID) technology has already revolutionised areas such as logistics (i.e., supply chains), e-health management and the identification and traceability of materials. The challenging concept of RFID-enabled logistics management and information systems is that they use components of the Electronic Product Code (EPC) global network, such as Object Naming Services (ONS) and the EPC Information Services (EPCIS) in order to support the Internet of Things concept.

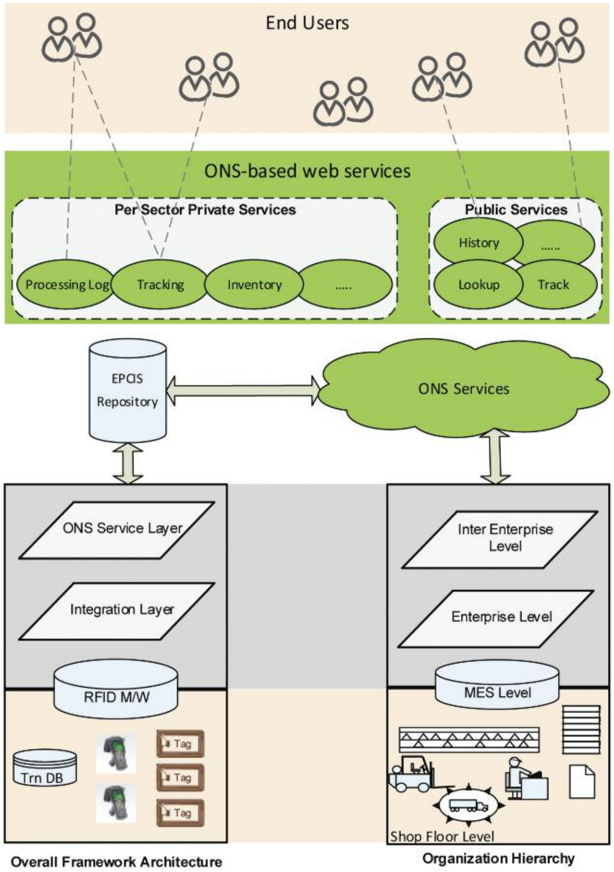

Figure 1: The architectural framework of SELIDA.

SELIDA is a joint research project between the Industrial System Institute, the University of Patras (Library and Information Center), the Athens University of Economics and Business, Ergologic S.A and Orasys ID S.A. This project introduces an architectural framework that aims to support as many of the EPC global standards as possible (Figure 1). The project's main goal is the ability to map single physical objects to URIs in order to provide, to all involved organizations in the value chain, various information related to these objects (tracking, status, etc). This is mainly achieved by SELIDA's architectural framework which is able to support as many of the EPC global standards as possible (Figure 1) along with the realization of ONS-based web services available in the cloud. This architectural framework is a value-chain agnostic which relates to:
- the common logistics value-chain;
- the physical documents inter-change value-chain; and
- in demanding cases, the objects inter-change value-chain.

The discovery and tracking service of physical documents that has been implemented exploits both ONS 1.0.1 and EPCIS 1.0.1, in order to allow EPC tagged documents to be mapped to the addresses of arbitrary object management services (OMS), albeit ones with a standardised interface.

The main constituents of the architectural framework are:
- The RFID middleware which is responsible for receiving, analysing processing and propagating the data collected by the RFID readers to the information system which supports the business processes.
- The Integration Layer which seamlessly integrates the EPC related functions to the existing services workflow.

While the existing legacy systems could be altered, such a layer is preferable because of the reliability offered by shop floor legacy systems in general.
- The ONS Resolver which provides secure access to the ONS infrastructure so that its clients can not only query the OMSs related to EPCs (which is the de facto use case for the ONS) but also introduce new OMSs or delete any existing OMSs for the objects.
- The OMS which provides management, tracking and other value added services for the EPC tagged objects. The ONS Resolver maps the OMS to the objects, according to their owner and type, and they should be implemented according to the EPCIS specification (see link below).

The SELIDA architecture has been integrated into KOHA, the existing Integrated Library System used in the University of Patras Library and Information Center. As with all integrated library systems, KOHA supports a variety of workflows and services that accommodate the needs of the Center. The SELIDA scheme focuses on a handful of those services and augments them with additional features. This is generally done by adding, in a transparent way, the additional user interface elements and background processes that are needed for the scheme to work. In order to provide the added EPC functionality to the existing KOHA operations, the integration layer was designed and implemented to seamlessly handle all the extra work, along with the existing service workflow. The SELIDA scheme provides additional functionality to services such as Check Out, Check In, New Record and Delete Record. There are also a number of tracking services that our scheme aims to enhance; these are History, Location and Search/Identify.

The implemented architecture focuses on addressing the issue of empowering the whole framework with a standard specification for object tracking services by utilising an ONS. Thus, the organisations involved are able to act agnostically of their entities, providing them with the ability to resolve EPC tagged objects to arbitrary services in a standardised manner.

Links:
KOHA: www.koha.org
ISO RFID Standards: http://rfid.net/basics/186-iso-rfid-standards-a-complete-list
Survey: http://www.rfidjournal.com/articles/view?9168
EPCglobal Object Name Service (ONS) 1.0.1: http://www.gs1.org/gsmp/kc/epcglobal/ons/ons_1_0_1-standard-20080529.pdf
EPCglobal framework standards: http://www.gs1.org/gsmp/kc/epcglobal

Reference:
[1] J. Gialelis, et al.: An ONS-based Architecture for Resolving RFID-enabled Objects in Collaborative Environments", IEEE World Congress on Multimedia and Computer Science, WCMCS 2013

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Lost Container Detection System

by Massimo Cossentino, Marco Bordin and Patrizia Ribino

Each year thousands of shipping containers fail to arrive at their destinations and the estimated damage arising from this issue is considerable. In the past, a database of lost containers was established but the difficult problem of identifying them in huge parking areas was entrusted to so-called container hunters. We propose a system (and related methods) that aims to automatically retrieve lost containers inside a logistic area using a set of sensors that are placed on cranes working within that area.

Figure 1: A common shipping area (by courtesy of Business Korea).

The Lost Container Detection System (LostCoDeS) [1] is an ICT solution created for avoiding the costly loss of containers inside large storage areas, such as logistic districts or shipping areas. In these kinds of storage areas (Figure 1), several thousand of containers are moved and stacked in dedicated zones (named cells) daily. Nowadays, the position of each stacked container is stored in a specific database that facilitates the later retrieval of this location information. As the movement and management of containers involves many different workers (e.g., crane operators, dockers, administrative personnel, etc.), communication difficulties or simply human distraction can cause the erroneous positioning of containers and/or the incorrect updating of location databases. In large areas that store thousands of containers, such errors often result in containers becoming lost and thus, result in the ensuing difficulties associated with finding them.

At present, to the best of our knowledge, there are no automatic solutions available that are capable of solving this particular problem without the pervasive use of tracking devices. Most of the proposed solutions in the literature address container traceability during transport (either to their destinations or inside logistic districts) by using on-board tracking devices [2] or continuously monitoring the containers with ubiquitous sensors [3], only to name a few.