THESIS ON MECHANICAL ENGINEERING E68

Laboratory as a Service
A Holistic Framework for Remote and Virtual Labs

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Laboratoorium kui teenus – kaug- ja virtuaallaborite holistiline raamistik

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> "Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any degree or examination."

Sven Seiler

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Thesis structure

This thesis is organized into the following chapters:

- Chapter 1 (starting at p. 8) provides the general background of the thesis and the work the thesis author was involved in during his doctoral studies.
- In chapter 2 at pages 19ff, the 'Holistic blended framework for Research and Education' with its components and subparts is introduced.
- Chapter 3 (p. 31) provides all background information about the 'Laboratory as a Service' concept, including the 'Lab Description Language' approach.
- In the following chapter 4, starting at page 43, the 'Virtual Micro Controller Unit' research is presented and illustrated.
- These parts are followed by the discussion and conclusion (p.53ff), giving an overview about the thesis research and implementation results.
- The five selected main publications (Paper A - Paper E, introduced on the next page) are placed on pages 65 to 118.

List of main publications

Journal publications

Paper A: Seiler, S., Sell, R. 'Comprehensive blended learning concept for teaching micro controller technology utilising HomeLab kits and remote labs in a virtual web environment'. Lecture Notes in Computer Science, Transactions on Edutainment, Number 7544, 2012, ISSN: 1867-7207, Springer, Germany (p. 65ff.)

Paper B: Seiler, S., Sell, R., Ptasik, D., Bölter, M., 'Holistic web-based Virtual Micro Controller Framework for research and education. International Journal of Online Engineering'. 2012. ISSN: 1861-2121 (p. 84ff.)

Paper C: Sell, R., Seiler, S., 'Improvements of multi-disciplinary engineering study by exploiting design-centric approach, supported by remote and virtual labs'. International Journal of Engineering Education. Volume 28. p.759-766., 2012. ISSN (printed): 0949-149X. ISSN (electronic): 0742-0269. (p. 92ff.)

Conference publications

Paper D: Seiler, S., Sell, R., Ptasik, D., 'Lab Description Language - a framework approach for describing and mediating remote and virtual labs'. 9th France-Japan & 7th Europe-Asia Mechatronics Congress and 13th International Workshop on Research and Education in Mechatronics, 21.-23.11.2012 (p. 101ff.)

Paper E: Sell, R., Seiler, S., 'Integrated concept for embedded system study'. In: Mechatronic Systems and Materials: 7th International Conference of Mechatronic Systems and Materials. (Eds.)I. Skiedraite, J. Baskutiene, E. Dragasius. Kaunas Technologija. 2011. p.14-23 (p. 107ff.)

1. Introduction

“I am trying to free your mind [...], but I can only show you the door. You’re the one that has to walk through it.”
Laurence Fishburne, *The Matrix*, 1999

1.1. Motivation and problem setting

Nowadays the engineering industry is characterized by rapidly occurring innovations and continuous advancement of existing technologies. Therefore, it is quite a challenge for research institutions to keep up with the high pace of technological advancements in industry by being up to date with facilities, educational concepts and curricula [1, 2]. According to Carew and Cooper, engineering is "a field where innovations in technology mean that /.../ connection between engineering curriculum and the technology used in industry need[s] constant attention."[3]. Where the utilization of modern technology is finding its way into our digital society, this evolution is accompanied by a lack of adolescent interest in taking part in scientific and technological development, as expressed in [4, 5] and [6]. The engineering qualification has to become more attractive to young people and feasible to full-time employees in order to stay at a high level in product development and to inspire potential engineering students. Engineering research, education and professional training is shaped by the utilization of practical hands-on experimentation facilities (called "labs" from here on), much more than in any other scientific discipline. A particular lab (e.g. an "industrial robot arm" or a "production line") might be too expensive to be purchased by a single research and engineering institution or too large to be placed in a small research facility. This raises the idea of sharing labs between different institutions as explained in [7]. Cooper and

Ferreira note about remote experimentation, "it appears to offer a simple solution to problems of distance, collaboration, expensive equipment, and limited availability." [8]. Gravier et al. further report other expectations in lab sharing, which are non-monetary and apply quite well for research applications, like "security", "observability", "dangerousness", "accessibility" and "availability" [7]. Taking hazardous research experiments into account, these could be achieved more securly by utilizing remote lab technology. The general idea of equipment sharing without enterprise or institutional borders supports the research scheme of *Factories of the Future* as it enhances industrial research through mediating access to expensive equipment for technology-driven SMEs or industry. One of such application can be, for instance, a research institution certified tests for industry with remote observation.

In the preface to [9], Zvacek summarizes the advantages of remote labs. According to her, "the benefits are likely to include increased /.../ access to equipment, greater flexibility in lab scheduling, a wider range of possible assignments of activities, and enhanced opportunities for collaboration /.../.". The authors' goal in [10] is "to use modern technology to provide students with enough learning opportunities to conduct science experiments that are essential to science education". M. R. Kadhum and S. Kadry notice the "lack of the modern laboratory in scientific institutes"[11] as a reason for the need to develop remote lab infrastructure. Henke, Ostendorff and Wuttke report about the remote lab's advantages: "it gives the student the possibility to work on real world systems without the need to stand in line at a lab or the need to take care of opening hours"[12]. Facer and Sandford argue that the educational development should "move beyond pedagogy to curriculum; beyond the school to the community, home and workplace"[13]. In a guest editorial [14], Auer and Gravier introduce the many facets of remote labs. Authors in [15, 16, 17] discuss the general role of labs in engineering science in more detail.

Summarizing these statements, remote labs offer various advantages over conventional labs, far beyond budget issues for both research and education.

There have been several attempts in the last decade to deal with the issues mentioned here. The goals of the iLabs project at Massachusetts Institute of

Technology in USA, were to develop a suite of software tools to facilitate online complex laboratory experiments, i.e., "minimize development and management effort for users and providers of remote labs, provide a common set of services and development tools, scale to large numbers of users worldwide, allow multiple universities with diverse network infrastructures to share access" [13, 18, 19, 20]. Authors in [21], have compared three web services based architectures of remote laboratories, DIBE ISILab (Internet Shared Instrumentation Laboratory), HPI DCL (Distributed Control Laboratory) and MIT iLab, according to user interactions and interoperability between remote labs. All of these architectures collect in a web service interface all the functionalities exposed by the lab, and use work sessions to structure measurements and store data sent or received from the instruments. The authors also stated that "structuring remote laboratory functions as a set of services has the major advantage of allowing the sharing of the physical experimental setup, while leaving the possibility of customizing the client application interface". Where most approaches [22, 23, 24, 25, 26] focus on a single lab integration, the authors in [27, 28] suggest a "Service Oriented Laboratory Architecture" approach. From the interoperability perspective, the authors have tested and proved the possibility of sharing remote experiments between different institutions [29], as did the consortium of the author of this thesis [30, 31, 32, 33, 34]. Currently, there is very little evidence for significant sharing of distance lab hardware between different institutions. Different facilities have their own technological approaches, so sharing is very complicated since external software components and data sources cannot be integrated into existing platforms without major expense.
The requirements in technical knowhow, programming skills and time are too high for most teaching staff. Furthermore, there are no common documentation sets, software platforms or reusable libraries to reduce the workload for a remote and virtual lab provider. The complexity of the common approaches delays the evolution of distance lab solutions and hinders a thematically wider range of potential lab providers and users from participating in distance lab networks.

As a result of this problem, there is an urgent need for standardization in this field. According to authors in [35, 36, 37] a more generalized approach is necessary to establish a wider use of remote labs in research and education. One important step in this direction is the development of a common language for the lab integration as well as a comprehensive soft- and hardware toolbox including documentation for automated plug and play distribution of remote and virtual labs (Paper A, [p. 65] gives an overview of different types of online accessible labs). In addition, there needs to be an adequate implementation of technology-enhanced learning in the practical orientated parts of engineering education by embedding these approaches into learning concepts. These attempts are presented in this present thesis in the subsequent chapters.

1.1.1. Presentation of concepts and introduction to the subject

During an on-going European-wide collaboration between different universities[1], containing a core team of researchers from Tallinn and Bochum, a novel and holistic approach for research and education of young engineers ("Holistic blended framework for Research and Education") in the two sectors of Mechatronics and Computer Sciences has been running since 2007. This approach is the main subject of this thesis. The novel concept involves a comprehensive framework for remote experiments and laboratory sharing for embedded system technologies with different focuses: a) research teams, b) digital factories and c) engineering educational institutions. This intensive research endeavor in the remote access of technical equipment through the Internet has been accompanied by the development of a novel modern web-based remote and virtual lab solution. These labs are built upon a descriptive framework named "Laboratory as a Service" with its "Lab Description Language" (LDL) (covered by Paper D, p. 101) that was formalized in the scope of this thesis. In addition, a virtualized micro controller framework named "Virtual Micro Controller Unit" (VMCU) (covered by Paper B, p. 84) was devised and implemented.

[1] Tallinn University of Technology, Tallinn, Estonia
Bochum University of Applied Sciences, Bochum, Germany
Ruhr University Bochum, Bochum, Germany
Aalto Korkeakoulusäätiö operating as Aalto University, Helsinki, Finland
Coventry University, Coventry, United Kingdom
Royal Institute of Technology, Stockholm, Sweden

Author's professional work contribution to the thesis The thesis author was engaged in the above-mentioned international team from the beginning; first as a student, later as subproject leader, being project manager and investigator of Bochum University of Applied Sciences project group for new projects by the end of doctoral studies. The overall collaboration finally led to a proposal for an "integrated project", with 17 partners from eight European countries, submitted to the European Commission in the frame of 7th Framework sub programme "technology-enhanced learning" in January 2012. The proposal was accepted as being eligible for funding, as the evaluation was notably above the threshold. Up to the date of thesis defense the author was involved in the following projects that are all contextually related to the thesis topic:

- "Advanced E-Curricula and Mobile Tools for Interdisciplinary Modular Study", Interstudy, 2007, 24 months
- "Modularization of the automotive study process by e-environment", Autostudy, 2008, 18 months
- "Modern Shared Robotic Environment", MoRobE, 2009, 24 months
- "Virtual Academy Platform for Vocational Schools", VAPVoS, 2011, 24 months
- "Learning Situations in Embedded System Study Lab", NETLAB, 2011, 24 months
- "Virtual & Distance Labs environment for Industrial Engineering Education", ViReal, 2012, 24 months

1.2. Main objectives

Finding and offering solutions for the problems described in section 1.1, the thesis author identified **five over-spanning objectives** to be solved in the frame of this doctoral thesis. These goals are covered by the subsequent chapters and the selected scientific publications in the annex. The five objectives are namely:

(i) *to research a formal description language for the specification of remote and virtual labs in engineering science,*

(ii) *to research a proper infrastructure for mediating internet-accessible labs and to identify and research necessary technologies and tools for interfacing and integrating remote and virtual labs into blended and distance learning processes,*

(iii) *to research and implement a framework concept for the creation of virtual embedded system devices,*

(iv) *to research and develop a holistic blended learning concept by utilizing remote and virtual labs in education,*

(v) *to implement and evaluate the researched technical framework (i.-ii.), developing a proof-of-concept by utilizing virtual embedded devices (iii.) and transfering this implementation to a real-world scenario, by connecting it to the blended learning concept (iv.).*

1.3. Research process plan

For the purpose of achieving the goals presented above, the following connected activities were carried out in the frame of this research:

Describing, mediating and interfacing remote and virtual labs

These activities are covered in chapter 3 and Paper D (p. 101), with an additional introduction to LDL in Paper B (p. 84).

(i) *Research and develop a "Laboratory as a Service" framework (LaaS) to offer a comprehensive method for the allocation and mediation of remote and virtual labs including interfaces to learning environments and a associated educational framework in the frame of engineering science*

(ii) *Formalize a concept of a "Lab Description Language" (LDL) to define technical aspects and interfacing of labs and their associated devices (e.g. camera) into a distance lab environment*

Holistic blended framework for Research and Education

These activities are covered in chapter 2, with mainly Paper A (p. 65) and Paper C (p. 92) and addditional content in Paper E (p. 107).

(iii) *Research and development of the "Holstic blended framework for Research and Education in Mechatronics and Computer Science"*

(iv) *Research and development of the Robotic HomeLab kit as a basic toolkit for education using the concept*

(v) *Development of add-on modules for the Robotic HomeLab kit*

(vi) *Creation of associated learning material for the concept*

Virtual Micro Controller Unit

These activities are covered in chapter 4, with mainly Paper B (p. 84) and introductory content in Paper A (p. 65).

(vii) *Development of the web based, distributed Virtual Micro Controller Unit (VMCU), with a graphical user interface, that allows simulations of AVR based microcontroller devices and a modularization of the system to extend it by further modules as an implementation of the LDL approach*

(viii) *Development of two virtual add-on boards for the VMCU unit ("User Interface Board", "Virtual Robot Arm") that can be utilized within the blended learning concept.*

Implementing and evaluating the developed approaches

This activity is covered in all chapters, with focus on the results in the chapters "Discussion" (chapter 5, p. 53ff.) and "Conclusion" (chapter 6, p. 60ff.) and Paper C (p. 92).

(ix) *Setting up a proof of concept of researched technologies and a concept for teaching embedded system technology.*

(x) *Evaluation of the pilot in daily education.*

Acknowledgement

FIRST of all I would like to thank my Ph.D. supervisors Raivo Sell and Prof. Rein Laaneots for constantly supporting me on all issues that arose. Especially, I'd like to thank Raivo for his guidance, support and encouragement during this thesis and for the friendship which evolved over time during our professional cooperation. In addition I´d like to thank Prof. Priit Kulu and Prof. Mart Tamre for their help.

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Last, but not least, a big '**thank you**' to the colleagues working together with me on the 'Laboratory as a Service' research proposal. Without your work this thesis would not have been the same.

“I declare I don't care no more”
Greenday, *Burnout*, Dookie (1994)

List of abbreviations

API	Advanced Programmers Interface
ARM	Advanced RISC Machine or Acorn RISC Machine
AVR	The AVR is a modified Harvard architecture 8-bit RISC single chip microcontroller
BLC	Holistic Blended Learning Concept
BLC-DC	'Learning Concept' of the Blended Learning Concept
BLC-LP	'Learning Path' of the Blended Learning Concept
btw	by the way
CAN	Controller Area Network
DCMI	Dublin Core Metadata Initiative
CESN	Coastal and Estuarine Research Federation
DC	Direct current
DCL	Data Control Language
DL	DistanceLab
DL2.0	DistanceLab 2.0 - The new version of DistanceLab, that is using LDL
DNS	Domain Name System
e.g.	*exempli gratia*, meaning 'for instance'
EC	European Commission
FOAF	Friend of a Friend
FP7	Framework 7 Programm, Industry and Research funding by EC
GPS	Global Positioning System, official: NAVSTAR GPS
GUI	Graphical User Interface
i.e.	*id est*, meaning 'that is to say'
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology

IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
JSON-RPC 2.0	JavaScript Object Notation Remote Procedure Call, Version 2.0
LaaS	Laboratory as a Service
LaaS-TC	'Technical Concept' of the Laboratory as a Service approach
LCD	liquid crystal display
LDL	Lab Description Language
LED	Light-emitting diode
LI	Lab Identifier
LMS	Learning Management System
MCU	Microcontroller Unit
NoE	Network of Excellence
NSDL	National Science Digital Library
OS	Operating system
OSS	Open Source Software
PLE	Personal Learning Environment
R&D	Research and Development
SME	Small and medium enterprise
SOAP	Simple Object Access Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TEL	technology-enhanced learning
UI	User Interface
UPS	Uninterruptible Power Supply
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
USB	Universal Serial Bus
VLE	Virtual learning environment
VMCU	Virtual Micro Controller Unit
W3C	World Wide Web Consortium
WSDL	Web Services Description Language
XAML	Extensible Application Markup Language
XML	Extensible Markup Language
XSD	XML Schema Definition

2. Holistic blended framework for Research and Education in Mechatronics and Computer Science

"If real is what you can feel, smell, taste and see, then 'real' is simply electrical signals interpreted by your brain"
Laurence Fishburne, *The Matrix*, 1999

The 'Holistic blended framework for Research and Education in Mechatronics and Computer Science' (BLC) consists of a technical and a didactical part. These parts are accompanied by those assisting technologies and material which are appropriate and necessary to learning and teaching. These segments will be described in the following sections, starting with the technical concept, followed by the didactical part and completed by an introduction to the learning material.[1]

The novelty of this blended learning concept is its completeness in covering all aspects of the educational process in engineering science. Common solutions offer hardware kits or learning material or virtual hardware, and even a combination of them. The BLC consists of a) a set of technological products to be applied in technology-enhanced learning (TEL) processes, b) ordinary face to face education in class, c) eLearning applications for access from outside the university, d) homework and e) practical student work in the form of group competitions.

[1]Parts of this learning concept description are based upon a paper of DAAAM International Vienna conference [34] by the thesis author, published in November 2011.

These technologies include a virtual hardware kit (see chapter 4 for more details) as well as the Robotic HomeLab kit. It is a comprehensive approach, starting with utilizing the VMCU, continuing with the real hardware, up to complex robotic contests (depending on the students' abilities). The overall concept is accompanied by freely accessible learning material and readymade learning situations that can be directly applied to the class. In addition there is a forum and wiki system, named 'Network of Excellence' (NoE), available to share experience in an international community. There is no other complete concept comparable to this available for Mechatronics and Computer Sciences. More detailed information, not covered in this chapter, can be found in Paper A (p. 65) and Paper C (p. 92) with additional content in Paper E (p. 107). Before covering the detail of the BLC, a state-of-the-art analysis of eLearning is presented in the next section ranging from the approach to existing learning concepts.

2.1. State of the art in eLearning education

Blended Learning [43, 44, 45] came into being to reduce the disadvantages of traditional learning approaches whilst avoiding the known failures of e-learning [46, 47, 48] by providing a combination of various learning strategies or models [49, 50, 51].

It mixes various event-based learning activities, including self-paced learning, face-to-face class teaching and live e-learning. Failure to use effective learning theories in designing and implementing learning activities has a negative impact on the learning quality and outcomes. Technology alone tends to focus on presenting learning content rather than on assuring the engagement of learners in learning activities and the effectiveness of the learning process [52]. Blended learning is now in evolution. Some researchers have referred to an integrated learning approach that involves intertwining of computerised activities (Web 2.0 tools, mobile devices, simulations) with face-to-face activities (small-group, lectures, field trips) [53]. Instead of emphasising single learning platforms or other applications, future learning environments will be hybrid entities that integrate physical and virtual, personal and collective, local and global as well as formal

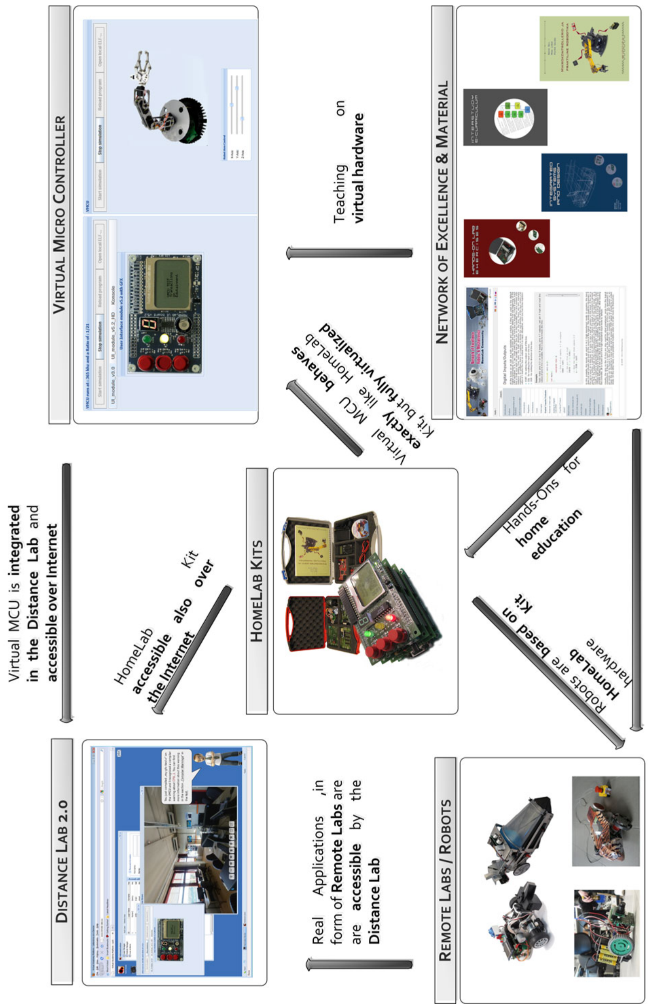

Figure 2.1.: Technical concept overview

and informal spaces for learning. Tools and environments for learning and collaboration have changed rapidly over the last few years, producing challenges in the field of TEL. For example, the emphasis on participation, peer production of content, dialogue and collaboration in Web 2.0 practices make them valuable elements in programmes focusing on the learner's active engagement - either individually or collaboratively - as a prerequisite for learning [54]. Personal learning environments (PLE) [55, 56] emphasise personalised, customised [57] and modular solutions to integrate personal and shared learning spaces. Several projects in the field of TEL have focused on developing learner-centred pedagogy (e.g. problem-based learning, inquiry learning, design-based learning). However, the critical challenge in designing today's TEL environments is that in often minimally structured environments, students may struggle to become engaged in productive learning activities and interactions (e.g. [58, 59]). Subsequently, learning-theory based and advanced pedagogical scenarios are needed, in addition to the important role of the teacher in supporting the knowledge construction process. In the field of TEL, some of the recent projects include a large umbrella project 'Kaleidoscope - Shaping the scientific evolution of Technology Enhanced Learning', a Network of Excellence project (FP6, 2004-08) [60, 61] and 'STELLAR - Sustaining Technology Enhanced Learning at a Large Scale', a Network of Excellence project (FP7, 2009) [62]. Other examples include the SCY (Science Created by You) project [63] that has created a system for the constructive and productive learning of science and technology. SCY is a flexible and adaptive pedagogical approach to learning, based on learning objects created by learners themselves. KP-Lab project [64] has focused on creating a learning system aimed at facilitating innovative practices of sharing, creating and working with knowledge both in education and in workplaces.

2.2. Technical concept

As stated in the introductory part of this chapter, the BLC consists of a technical and a didactical part. The different pieces of the technical conceptual part are illustrated in figure 2.1. The idea is based on utilizing various technology and media in the education of Mechatronics and Computer Science to enhance the overall learning process. The encompassing material includes micro controller hardware kits, the previously mentioned Robotic HomeLab kit with various add-on boards, accompanied by a virtual, simulated version, the so called Virtual Micro Controller Unit. Based on the HomeLab kits moving robots can be constructed, using the same hardware as the modules in the kit. The kits themselves, the robotic applications and the VMCU are accessible through an Internet platform, named DistanceLab, that also offers interfaces to various other labs which are integrated and mediated through the newly developed Lab Description Language (LDL). These hardware parts are completed by overarching teaching and learning material accessible through the Network of Excellence (NoE), a wiki-based platform providing learning situations and exercises amongst others. In the scope of on-going projects the DistanceLab functionality is being transferred into a new, collaborative platform and enhanced by various open-source tools. This platform looks and behaves like a desktop system but is fully based on modern web technology, easily accessible through any web browser via internet connection.

Initially, the main idea was built upon the Home Lab kits hardware, self-developed hardware packages, presented by [33] and [32] in detail. Through the work of subsequent projects this concept was widened to a more generic approach, thus enabling other hardware to become accessible over the DistanceLab web platform.

2.2.1. Robotic HomeLab kit

The Robotic HomeLab kit (see fig. 2.2 and Paper A) is a small ready-to-use test stand, packed into a handy case, which can be connected to a PC and operated in computer class, home or workplace. The aim of the kit is to provide practical and effective hands-on training. Students can combine various solutions on different levels of complexity and functionality based on the modules inside the kit. The main feature of HomeLab kit is its portability - it is small and compact with all modules and necessary tools included in the box. Looking at its status in current development, the HomeLab kit offers, for example, hardware and exercises for 7-segment LED displays, graphical LCDs,

Figure 2.2.: Robotic HomeLab kit and robotic applications

sensors (temperature, light, infrared, ultrasonic, etc.), different motors (DC, servo, stepper), as well as a networking module (for Bluetooth, Ethernet and ZigBee). The advanced HomeLab kit based on an ARM controller offers, in addition, CAN, USB and networking functionality targeted at the automotive and advanced robotic sector. Simple and easy to install software is used to connect the main controller to the computer. The software is a combination of commercial (but free) software and open source software, supplemented by a complete free development tool set for Windows, Linux and Mac platforms developed by consortium members. This is particularly important because the learner can start practical experiments in class and then continue the work at home or even at his/her workplace without bothering himself with licensing and software fees. Experiences from former projects, where pilot tests were performed in various countries, demonstrated a quicker start-up while working with the HomeLab kit than with other conventional solutions on the market.

An important part of Robotic HomeLab kit is a specific developed open source software library which is available[2] to all users. The library enables much easier access to peripheral devices and users do not have to bother with complicated register programming which is a usual part of micro controller software development. One may bring forward the argument that programming the registers is absolutely essential for understanding the nature of the micro controller but in a real life situation this quite often limits the time and other resources which can be available for study. By using the software library, the student can pay more attention to the system behavior logic instead of trying to have precise control over the controller by manipulating the registers. However, the basic knowledge about them is essential and therefore the first lab is usually done without using the library. The link between the DistanceLab and the Robotic HomeLab kit is that most devices in the DistanceLab use HomeLab Kit hardware components. Therefore it is possible to practice at home with a single function and then get access to more complex systems over the Internet to continue the training. In addition, there are of course other robotic and embedded system solutions available for teaching purposes. Other important ones are likely to be the *The Player Project* [65, 66, 67, 68] or *Arduino platform* [69, 70, 71, 72, 73] but the advantage of the HomeLab kit is the combination of hardware with associated teaching & learning material.

2.2.2. Virtual Micro Controller Unit (VMCU)

A method to realize a well-designed remote lab is the concept of virtual laboratories, where simulated versions of commonly used lab hardware are provided via the internet. These virtual labs are (almost) virtual clones of real lab equipment utilised in universities, high school or vocational educational institutions. The solution presented in this thesis is a web based virtual micro controller, as described in [31] and [74]. Additional virtual hardware components that can be plugged into the controller have been created in the frame of the development. The whole system is a modular software framework that contains enhanced controller modules as well as add-on components such as displays, LEDs and motors. To use this framework for study purposes, the handling of

[2] The open source library can be downloaded from `http://home.roboticlab.eu/en/software/homelab/library`

all virtual components was designed to be almost exactly equivalent in behavior to real hardware. The interconnection of the virtualized micro controller and the associated add-on boards is mediated using an early version of LDL. The VMCU concept will be introduced further, in chapter 4, as it is one of the main outcomes of this doctoral thesis.

2.2.3. DistanceLab

The DistanceLab utilized from the beginning in the BLC is based on an early form of the LaaS concept and is one example for a 'Lab Provider' (see chapter 3). The developed solution is intended for research and educational use. It consists of a web platform and a set of hardware providing access to remote labs which can, but do not necessarily have to, be based upon the HomeLab Kit hardware. The DistanceLab is designed for facilitating direct programming of the connected devices. This is realized by using a web based programming editor and an automatically invoked compiling process; enabling flashing programs to the connected devices over the internet. Some examples for interfaced labs are the robotic applications (via wireless flashing), specific versions of HomeLab Kits with add-on modules for a specific purpose (for example automotive study CAN-Module, LCD Display or a motor board) or the Virtual Micro Controller System with its various modules. In the case of real hardware labs, the user can monitor the behavior and control the compiled program by accessing cameras showing the lab in real time. In the case of virtual hardware, specific pieces of software are used for the user interface and process data visualization to captivate young engineers. The platform is currently evolving further to a new version named 'DistanceLab 2.0' based upon the LaaS concept. The current development status is presented in fig. F.1 on page 123 and fig. F.2 on page 123.

2.3. Didactical concept

2.3.1. Blended Learning concept

The didactical part of the concept consists of a strategy for implementing the blended learning concept in daily education and a set of learning materials. The two figures 2.3 and 2.4 illustrate the coherences between the technical concept parts and their application in the pedagogical context. Figure 2.3 is based on two roles, "Teacher / Instructor" and "Student / Learner", where their point of intersection is the Network of Excellence, that is described in section 2.5. Teachers' tools consist of a teaching methodology, pedagogical collaboration with other teachers in an international platform, supervisor specific content, available through NOE and teacher training (for instance 'train the trainer' seminars), enhancing a teacher's knowledge of usable and available tools and content. The learner's side is supported by textbooks and lab guides and other eLearning material, which are freely accessible online through NoE. In addition, the HomeLab kit, DistanceLab and VMCU builds are the tools for this, leading to a robotic contest or joint student projects utilizing the introduced material. The overall goal of the concept is to extend the knowledge of integrated systems and learners' practical skills. This part is mainly covered in Paper C and Paper E.

2.4. How the technical and didactical part complement each other

The idea is that students can develop software using a regular programming tool (such as AVR Studio or Eclipse) and run this software on virtualized hardware. Since the program code will be developed with a standard tool, it will work on real hardware as well as it does on virtual hardware. This way students get practical experience in programming that can be applied to real world problems and applications. The sequenced utilization of the tools in the concept is illustrated in fig. 2.4. Learners will be assigned a task by the instructor that involves all important parts of the system. The task will be first performed on a VMCU device that is available in multiple instances, only limited by the com-

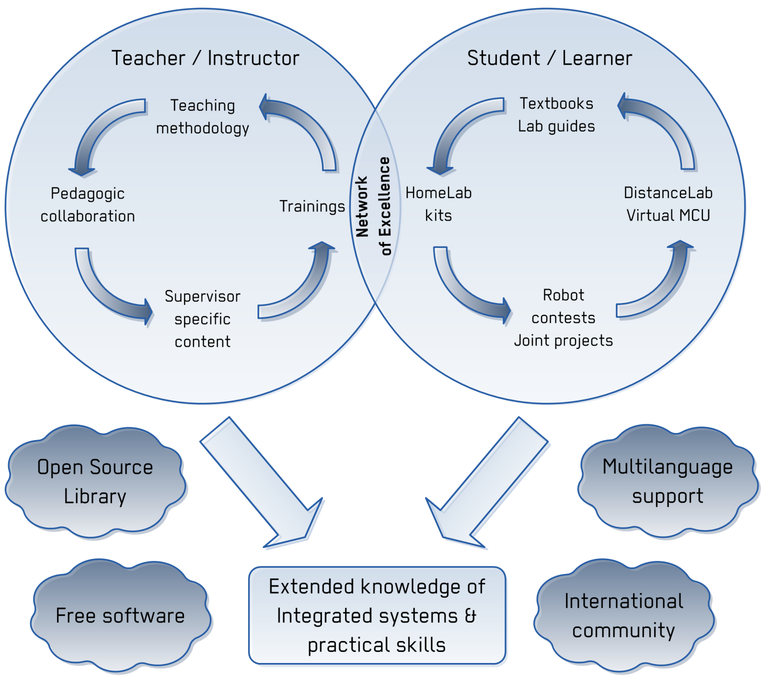

Figure 2.3.: Didactical concept

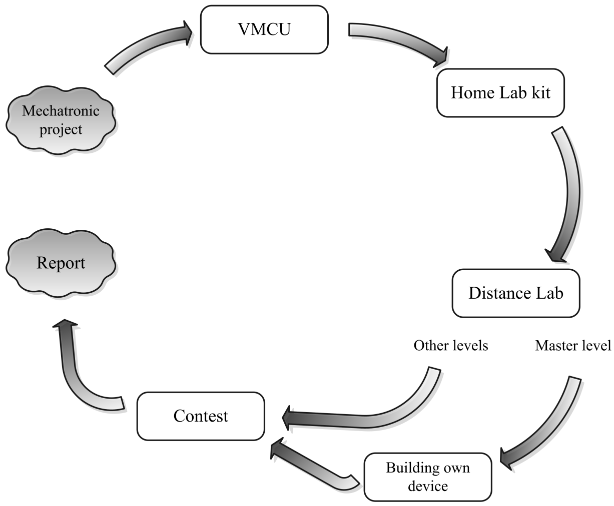

Figure 2.4.: Coherence between the different concept levels

puting power of the student's machine and the connection rate of the server where the VMCU is located. Once students are familiar with the hardware, they can test and evaluate their solution on the HomeLab kits. The penultimate step differs depending on the learner's educational level. Master students in Mechatronics will continue with a robotic contest in student groups, building robotic applications based upon HomeLab kit hardware. All other users continue their practice by using robots available through the DistanceLab lab.

2.5. Network of Excellence (NoE)

The Network of Excellence (NoE) [75] is a wiki page hosting learning materials, teaching methodology and software for robotic studies. It is also called 'Robotic HomeLab Community' and is a support system for utilization of Robotic HomeLab kits for users and teaching staff. The site includes material such as programming examples, theory about components, overview of the hardware and overview of the software. The website has a forum for discussions and wiki pages for user contributions. The NoE has a special section for teachers which includes the teacher training material and, most importantly, the exercise solutions and answers to revision questions. In the Robotic HomeLab Community the consortium intends to have all learning material, and also the teaching methodologies, directly accessible for interested learners and teachers; as well as a ready-to-implement curriculum for the vocational schools to apply our solution directly in school, which is the main strength of our approach. The overall page is a multi-language system, where English is the original language from which translations are made. Access to the international community is available using six other languages (Estonian, German, Finnish, French, Lithuanian and Russian). The next language for translation will be Turkish. The strength of this website is the number of teaching aids contributed by teachers and developers from different European countries, and therefore with the influence of various cultures, levels of knowledge and styles of teaching, which leads to a comprehensive set of supporting teaching material. A new section, which is currently under development, will provide a set of learning situations with full methodology.

3. Laboratory as a Service concept and Lab Description Language

"You take the blue pill - the story ends, you wake up in your bed and believe whatever you want to believe. You take the red pill - you stay in Wonderland and I show you how deep the rabbit-hole goes."
Laurence Fishburne, *The Matrix*, 1999

The Laboratory as a Service concept (LaaS) will bring new technology approaches into the provisioning of remote and virtual labs, by integrating plug and play remote and virtual experimentations combined with knowledge assessment and representation systems conforming to an overarching innovative technical and educational framework.
LaaS is the overall name for the concept, including all necessary technologies for a comprehensive solution in lab sharing and integration of associated learning material. Where BLC, presented in chapter 2 with its specific implementations of technologies (for instance the 'DistanceLab platform'), is a variant of LaaS, **the LaaS itself is a framework concept, formulating basic conditions for remote and virtual lab sharing**. LaaS offers recommendations for best-practice technologies, like LDL, but is not itself an implementation.

A detailed overview of these framework approaches can be found in Paper D (p. 101), with additonal content in Paper B (p. 84). Furthermore, the LaaS conceptualization was transferred to an FP7 application in the frame of "technology-enhanced learning" that was approved for funding in May 2012. Before introducing different aspects of LaaS, a detailed state of the art analysis of remote and virtual labs technology is presented in the next section.

3.1. State of the art in remote and virtual labs

To solve the problem of providing practical skills to students despite the lack of equipment and funds in educational institutions, technology enhanced learning based on the sharing of equipment between institutions is suggested for wide-scale implementation across European countries [7], [80]. Advances in internet-based technologies allow institutions, SMEs and private individuals to access the equipment of other organizations. However, the main problem today is that there are no standards or recommendations regarding the requirements for such equipment (electrical signals, communicational protocols and compatibility of software). There are merely some suggestions ([81], [82], [80]) but no DIN, ISO, or IEEE standards. Changing the view to subparts and subsystems, there are some existing (semantic) descriptions for various science areas, such as sensor descriptions. For instance, in 2009 Compton et al. analyzed in [83] 12 different sensor ontologies. While some of them (like Avancha [84] and CESN [85]) are merely descriptions of sensors, other like OntoSensor [86] are also capable of describing 'components', or like OOSTethys 'processes' in addition. Their conclusion gives the statement that a "combination of OntoSensor and the CSIRO ontology represents the current limit of expressive capability for semantic sensors" [83], but none of them is able to deal with the whole context of sensor descriptions.
For user interfaces it is almost the same situation. Various descriptive approaches exist and are discussed in the Model-Based User Interfaces Incubator Group at W3C. These approaches can be separated into industrial (Collage, Flex, Open Laszlo and XAML for instance) and research driven (CAMELEON Reference Framework, MARIA and UsiXML for instance) ones (compare: [87]). Universities across the world are developing different types of remote labs for their own interests [7, 88, 89]. However, there is very little evidence at the present time that such local labs are used by other institutions in order to provide educational support for a wider range of students on a regular basis. The common web browser is widely used to access remote and virtual laboratories [90, 91]. Authors in [92] have introduced the concept of "experiment as a service" and developed a service-based software infrastructure for remote laboratories, called DCL (Distributed Control Lab). Examples of integrated experiments

available on DCL are "Higher Striker" (a real-time control experiment), a programmable logic controller and embedded real-time control applications. This work has been undertaken under the Vet-Trend project [93], with the main objective to build an open infrastructure for conducting robotics and real-time control experiments from the Web. Unfortunately, this concept has not become widespread so far since there is no established standard and the software components used in DCL are not publicly available.
Authors in [94], under a project called VISIR (Virtual Systems in Reality), developed software to allow users in various universities and other organizations to set up online lab workbenches for electrical experiments. The software is used by two universities and students can perform simultaneous experiments on online workbenches. Several other virtual and remote laboratories have been developed for a variety of disciplines [21, 95, 96]. However, the diverse proprietary interfaces, software components and implementations for each experiment are a problem for learners and teachers (no common user interfaces and APIs are used). Therefore, it is hard to integrate new remote labs or create virtual labs. Due to incompatible software implementations it is a hard task to integrate external labs into an existing lab platform. That complicates the sharing of labs between different organizations and universities.
Another major problem that slows down the evolution and distribution of distance labs is that very few qualified staff members are capable of providing lab equipment on the internet, not to mention that it is even more complicated to completely virtualise given hardware components. A strong indicator for this is that most of the distributed labs are engineering related; teachers from other disciplines who lack an affinity to programming are less likely to provide their labs on the internet since they lack the technical knowledge and support to do so. Most of the existing Labs are tailored lab-specific experiments (for instance: [97, 98, 99, 100]) and use diverse proprietary interfaces and implementations but there is no common user interface and no common APIs, nor a common description of them. Despite that, many labs share similar requirements; new experiments require new developments, logic, connectors and user interfaces. In other words, technologies used in current labs mainly lack reusability and interoperability, for instance they are not generic enough to be reused when designing and integrating new Labs. Also, most lecturers do not have wider

experience in interfacing existing Labs, mainly developing client user interfaces.

3.2. Laboratory as a Service

Currently, as stated in the previous section, there is very little evidence for significant sharing of distance lab hardware between different institutions. The lack of common standards in lab definition and connectivity specifications is a major impediment to the adoption and wide-scale networking of labs for teaching and training purposes. Research and educational facilities have their own technological approaches, so sharing is very complicated since external software components and data sources cannot be integrated into existing platforms without major expense. The requirements in technical know how, programming skills and time are too high for most staff. Furthermore, there are no common documentation sets, software platforms or reusable libraries to reduce the workload for a remote and virtual lab provider. The complexity of the common solution delays the evolution of distance lab approaches and hinders a thematically wider range of potential lab providers and users from participating in distance lab networks. As a result of this problem, there is an urgent need for unification in this field. This is, where the LaaS concept comes in. A graphical overview of the overall concept is provided in fig. 3.1 and a hierarchical technical system overview is presented in fig. 3.2. The overall system concept includes more than the technical approaches this thesis focuses on. In addition, the LaaS system framework has an underlying training concept that offers training material for the application of remote labs in research and education. Above this training approach, the technical concept solution is built up, having interfaces to Intelligent Tools for Labs and an Evaluation and Validation of LaaS. These parts are not covered in this thesis.

3.2.1. LaaS components

LaaS should be understood as a hierarchical plug-and-play approach for mediating and interfacing remote and virtual labs. The system is built upon existing web standards and open source tools, offering an *Infrastructure as a Service* (IaaS) approach, following the idea of ubiquitous computing. The next three

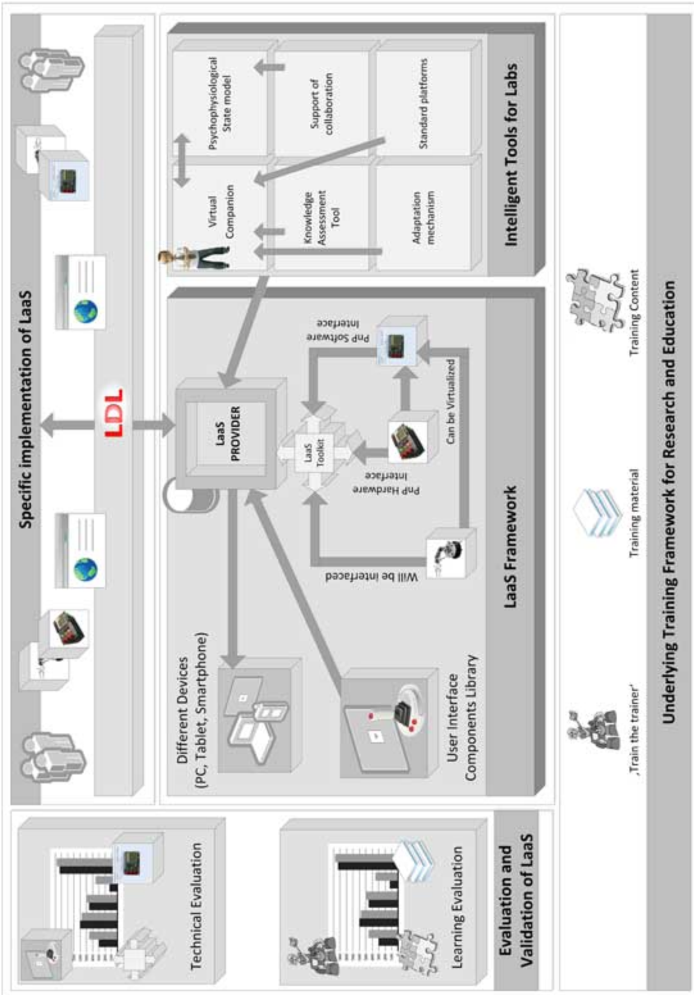

Figure 3.1.: The overall full LaaS concept including Intelligent Tools for Labs

sections briefly introduce the main components of LaaS, followed by a more detailed covering of the Lab Description Language (LDL) in section 3.3. An overview of the hierarchical structure of LaaS is presented in fig. 3.2.

LaaS Provider

The *LaaS Provider*[1] is the master server system and a repository for mediating labs and the universal access point for browsing existing online accessible experiments. The LaaS Provider offers web services for registering labs to the repository, for accessing and for updating them, amongst several others. For security reasons only a registered Lab Provider is allowed to register new labs to the LaaS provider. The LaaS Provider will enable cross-institution lab sharing as presented in section 1.2 available for everyone. Expensive hardware labs will have a significantly higher average use, supporting less well-equipped institutions.

The LaaS Provider is not meant for integrating labs into a LMS or other educational systems, but for the technical provisioning of them. Certainly labs can be interfaced through the web services LaaS Provider offers. Additionally LaaS offers a booking system for specific labs and a lab rights management system. These two systems are not for the end user level, but offer the lab services on an institutional level. The overall LaaS system is a structured hierarchy, in the same way the Domain Name System (DNS) is, following a basic taxonomy of lab equipment. Using that approach, a single lab can be addressed directly by knowing its Lab Provider and the Lab Location it is placed in, through its unique Lab Identifier (LI) (see listing 3.1 and section 3.2.1). The LI follows the URI concept. It can be accessed by the scheme 'lab://' or via the 'http://' scheme in any web browser. While the 'lab://' scheme directly addresses the web services on the specific IP address, opening the 'http://' instead for the same lab will display information about the specific lab or Lab Provider. The idea of the LI is presented in the following listing 3.1, with a concrete lab example situated at the Institute of Computer Science in Bochum, in the corresponding listing 3.2.

[1]The LaaS Provider will made be accessible for the scientific community through `http://online-labs.eu`, when it is adequately implemented.

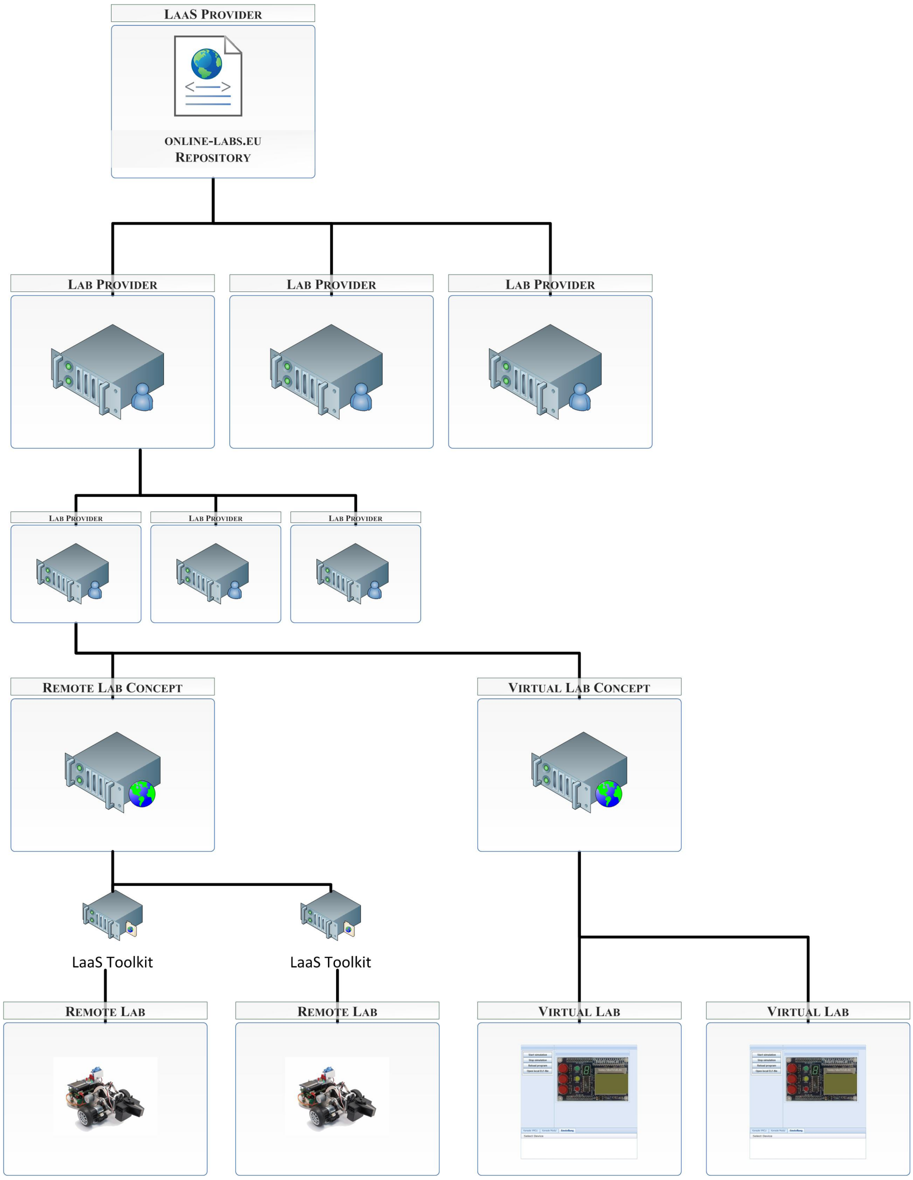

Figure 3.2.: LaaS System structure from a technical point of view

Listing 3.1: Lab Identifier Approach

```
lab://LaaSProvider/LabProvider[1-n]/LabConcept/SpecificLab[1-n]/
```

Listing 3.2: Lab Identifier Example

```
lab://online-labs.eu/de/universities/bochum-university-of-applied-sciences/
    department-of-electrical-engineering-and-computer-sciences/institute-of-
    computer-science/robot-arm/12/
```

All web services available through the LaaS provider are based on WSDL 2.0, communicating using SOAP.

Lab Provider and Lab Location

A Lab Provider is a local server system managing a collection of labs. The Lab Provider may be available at the institutional level or may span several institutions, offering a lab collection to the LaaS provider, which is the overarching system. A Lab Provider must be officially registered to the LaaS Provider for offering labs through it. Otherwise it might be coupled to another Lab Provider in a hierarchical way. This can be the case, if several Lab Provider are available within one institution, for instance when in one faculty several departments are setting up their own Lab Provider system. In that case the labs should be bundled first on a faculty level and then on the institutional level. One special case of a Lab Provider is a Lab Location, representing a collection of labs on the lowest level in one institution. From a descriptive point of view they are the same, but a Lab Location cannot have any child that is a Lab Provider.

Lab Concept, Lab Toolbox and specific Lab

A Lab Concept is a set of labs offering the same experiment. A specific place may offer several labs, for instance a ’remote controlled robot arm’ or version of VMCU with specific developed modules, which are available more than once. In this terminology a *Lab* is the smallest unit, offering one specific instance of a Lab Concept. As explained before and in more detail in chapter 4, there are virtual, remote and hybrid labs available. Where the virtual lab software can in most cases be changed or interfaced, hardware based labs need special attention.

Lab Toolbox To ensure an "as a service" approach within the whole concept, including hardware based labs, there is a need for small access servers, named Lab Toolboxes, offering a standard set of web services and which are required to act as a lab service provider. A Lab Toolbox system can be applied to any desired hardware system. Current approaches utilize Alix Boards[2] and Raspberry PIs Model B[3] as they are inexpensive. Both support an open source OS, offering the interface of additional devices through USB and PIN connectors to extend the hardware or the attachment of further electrical components (for instance - switches for turning an experiment on, Bluetooth, ZigBee or Wireless Lan). Both Alix Board 1D and Raspberry PI Model B support webcam streaming through common open source software solutions like *mjpeg_streamer*[4] and are equipped with Ethernet network interfaces. In the author's consortium they were several times successfully used as Lab Toolboxes. As mentioned before, these are best practice solutions; a Lab Toolbox can be any other hardware or software platform, so long as it is able to offer the necessary communication web services. This approach enables the easy plug-and-play of new labs to the LaaS network[5]

3.3. Lab Description Language

The lack of a common standard is also responsible for poor participation in distance lab projects. The requirements in technical knowhow, programming skills and time are too high for most teachers and university staff. Furthermore,

[2]Alix Boards are a Trademark of PCEngines `http://www.pcengines.ch`

[3]The Raspberry Pi is a small ARM based system, developed by the Raspberry Pi Foundation, available for less than 30 EUR - see: `http://www.raspberrypi.org`

[4]MJPEG

[5]Currently a Debian Linux is under development being adjusted for application as a LaaS ToolBox, offering standard webservices and already prepared for interfacing external devices through PIN connections. These ready-made versions will be deployed soon as flash images for both hardware platforms for download from `http://online-labs.eu/`.

there are no common documentation, software platforms or reusable libraries to reduce the workload for a distance lab provider. That is the main reason for low participation rates and also the reason most lab providers are from software engineering related fields. The complexity of the common approaches delays the evolution of distance lab approaches and hinders a thematically wider range of potential lab providers and users from participating in distance lab networks. It is the goal of the thesis authors to solve the existing problems in lab sharing (introduced in sections 1.1 and 3.1) by providing a draft for a descriptive lab integration, namely LDL. Based on common usage, it seems nonsensical to provide a roughly new description language, without taking existing approaches into account. Therefore the rudiment is based on XML Schema, formulating dependencies in remote and virtual lab architecture. Based on this descriptive language, LDL is extendable by linking to other concepts. For a future version it is currently planned to add the formal description of user interfaces to the overall concept. The following listing (listing 3.3) is presenting a subset of a WSDL Lab Concept formulation.

Listing 3.3: WSDL Lab Description (part)

```
[...]
 <xs:element name="LabConcept" type="laas:LabConceptType"/>
 <xs:complexType name="LabConceptType">
  <xs:sequence>
   [...]
   <xs:element ref="dct:educationLevel" maxOccurs="1"/>
   <xs:element ref="laas:scientificArea" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:complexitiyLevel" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:difficultyLevel" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:minBookingTime" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:maxBookingTime" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="dct:license" maxOccurs="1"/>
   <xs:element ref="dct:isPartOf" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:labstatus" minOccurs="1" maxOccurs="1"/>
   <xs:element ref="laas:observable" minOccurs="1" maxOccurs="1"/>
   [...]
   <!-- In the LDL implementation of a specific lab each webservice needs to be
        described in detail-->
   <xs:element ref="laas:webService" />
```

```
    [...]
    <xs:element ref="laas:url_lab_documentation" />
    <xs:element ref="laas:url_lab_tutorial" />
    <xs:element ref="laas:url_additional_information" />
    <!-- Future plan is to include booking to the LaaS system
    <xs:element ref="laas:BookingPrice" minOccurs="1" maxOccurs="1"/>
    -->
    [...]
   </xs:sequence>
  </xs:complexType>
[...]
```

As described before, LDL is a proposal for the integration of remote and virtual labs, their interfaces and web services, as well as the association with appropriate knowledge. In the light of current research the focus is on the technical mediation. The concepts offer synergic effects through the sharing of expensive hardware. LDL can be an institution-wide approach for mediating remote and virtual labs. Keeping a standardization of all distance/virtual lab communication interfaces in mind these need to cover the following aspects:

- Standardized description language for lab equipment
- Standardized communication between lab hardware and the lab PC
- Standardized communication between the lab PC and the server (plug-and-play of labs)
- A unified method to easily integrate Labs into every web platform (laboratory as a Service concept)

These web platforms can be any learning management system, such as Moodle or Blackboard, or it could be the homepage of a university or even a private web site. Integration of labs will be possible on every web platform that meets certain technological requirements. LaaS and LDL allow transparent access to laboratories independent of the type of system, because LDL allows labs/experiments to be defined in an abstract manner. LDL provides the data interchange basis to develop a web-based platform incorporating a comprehensive toolbox of components, component-interfaces and access interfaces. The standardization of required interfaces and the development and free distribution of software components for lab integration and distribution solves the major problems described above.

More examples about LDL and LaaS are presented in section F at pages 118ff.

LDL currently supports the Dublin Core Metadata Initiative (DCMI), DBpedia, Friend of a Friend (FOAF), National Science Digital Library (NSDL) and references to GPS positioning schema.

4. Virtual Micro Controller Framework

"What is "real"? How do you define "real"?"
Laurence Fishburne, *The Matrix*, 1999

4.1. Introduction to virtual labs

VIRTUAL labs are reflections of real labs but in a simulated environment.[1] The main difference, in comparison to a real lab, is that the experiments are not connected with real hardware but with a simulation engine. However, in some cases the user can hardly see the difference as virtual and real labs can share the same front-end user interface. The feedback from a real lab is usually provided by real-time video whereas a virtual lab provides an animated stream from the simulation engine. The server can generate as many instances of particular devices as required or allowed. In most cases, virtual labs are developed for each of the real remote labs, thus enabling an alternative way of accessing expensive lab equipment and overcoming possible issues about safety and security.

4.2. Virtual Micro Controller Unit Framework

The VMCU is just such a virtual lab device, based on the Robotic HomeLab kit introduced in section 2.2.1. It is a full-featured web-based virtual micro

[1] This text uses text pieces from the written course work of 'Synthesis of a Mechatronics System' from authors PhD studies, as well as some content from the 'Laboratory as a Service' proposal.

controller, behaving like the real hardware pattern.

One problem in the education of micro controller technology is the need for (quite often) specialized hardware for labs, which are (in total costs) quite expensive. In addition, when starting a new embedded system course the chance of them being broken by students is quite high in the early days. So a logical conclusion is to develop a virtualized micro controller simulation framework that is able to simulate different types of devices. To utilize the approach in a scientific and educational environment as a virtual lab and, by ensuring a high level of attractiveness, to fascinate young engineers with this technology, it is quite important that the system design is internet based. Following this approach, the virtual controller can be included in the DistanceLab, or any other Lab Provider platform, in the same way as real hardware by using LDL. The VMCU concept is covered mainly by Paper B (p. 101) and slightly in Paper A.

4.2.1. VMCU Design conditions

To develop the VMCU as a virtual lab accessible through a Lab Provider, the technologies appropriate for the simulation framework are limited. Besides that, there are additional framework conditions concerned with the future purpose of utilizing the VMCU. Those are discussed in [74].
The first requirement is to have the VMCU running in a platform accessible by any common web browser. The second requirement is to enable the VMCU working with "normal" binary files, so a common *C* language development environment can be used for programming the VMCU. The third framework condition concerns the cost of the system; the idea being to develop and deploy the VMCU framework as inexpensively as possible and without any annual/recurring fees. For demonstration purposes and to ensure its attractiveness, a graphical version of the controller must be realized; textual output alone is not sufficient, thereby setting a fourth condition. As a fifth condition, the general system behavior of the VMCU should be comparable to real hardware that exists in the Robotic HomeLab Kit. The final condition concerns the Distance Lab; it is planned to have the VMCU unit included in the DistanceLab or any

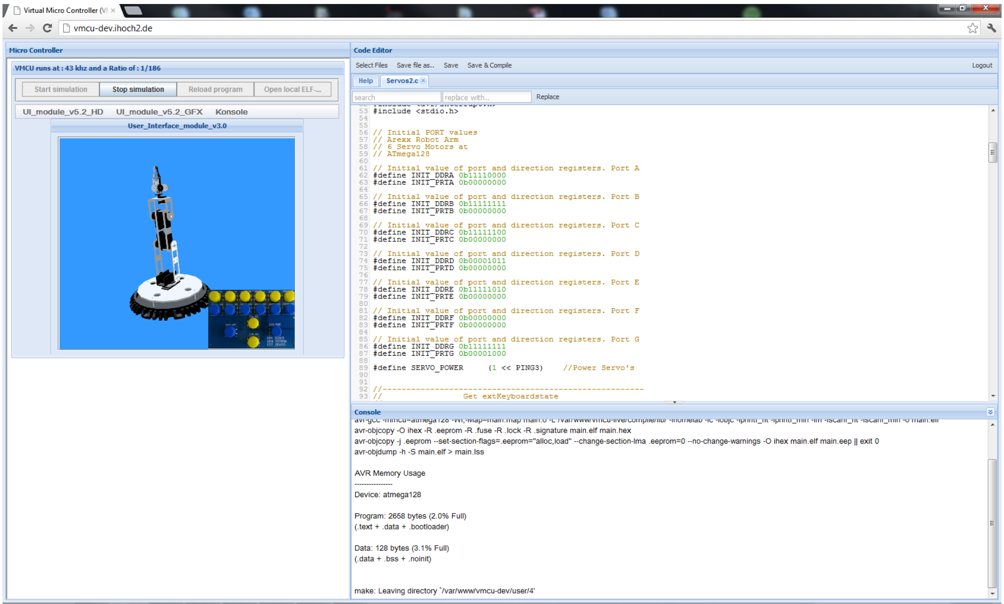

Figure 4.1.: The VMCU module 'Robot Arm' with programming environment

other Lab Provider environment. As a result the choice of programming languages to develop the whole system is, to some extent, limited. Thus the virtual version of the Robotic HomeLab kits was finally based on Avrora [104, 105], and Java. Today it is a fully functional, but virtual, micro controller running in any common web browser. The VMCU framework can be used for prototyping and the simulation of complex behavior as well as for educational purposes. The current development status is shown in figure 4.1, presenting a virtual robot arm on the left and the programming editor on the right side. On the lower right side the feedback of the compiler is displayed. Being modular, the VMCU base can easily be extended by new modules that can be integrated using LDL. The VMCU is the precursor to the HomeLab kit by its application in the BLC, as presented in sections 2.2 and 2.3.1.

4.3. State of the art in virtual micro controller technology

As stated before, the VMCU is based upon Avrora, which was chosen as a base platform out of several different available solutions. This state of the art analysis was performed in [74] and is summarized in this section. There are several virtual micro controller frameworks available, all of which are capable of simulating an *ATmega128*-micro controller by *Atmel* (the base controller used with the Robotic HomeLab Kit) and are ordered by closed source development environments with integrated simulator and free open source software.

The commercial simulations presented in table F.1 in the Annex F on page 121 are most likely expensive and closed source and cannot be easily extended by own-built plug-ins or modules. And so they do not fullfill the requirements for simulating the Robotic HomeLab kit. There are also several open source and free products available, presented in table F.2 (p. 122). Most of the free products mentioned are open source in their nature, which enables them to be customized as required. It is disadvantageous that some of the simulation environments are rather old and not maintained any longer. For that reason they are not taken into account for further development. Two of the simulators look quite interesting and promising, so they are both worth consideration to be enhanced for the main idea. These two are *AVR Studio* and *Avrora*. The main reason for choosing *Avrora* is, that this environment is built with the Java programming language and for the reason the source code is available for changing the general system behavior. The problem with most of the existing solutions is that they only focus on register values and time dependant output states. There is no common accepted visualization to this. Also a step-by-step execution of the code is not possible, as it is possible with real hardware.

As the Avrora framework has been chosen, Java has been set as the project's programming language as well. Since the technology is Java and the fact that the system should be integrated into a web page, inter applet communication for the system can be applied. The general approach of a simulation device is illustrated in fig. 4.2.

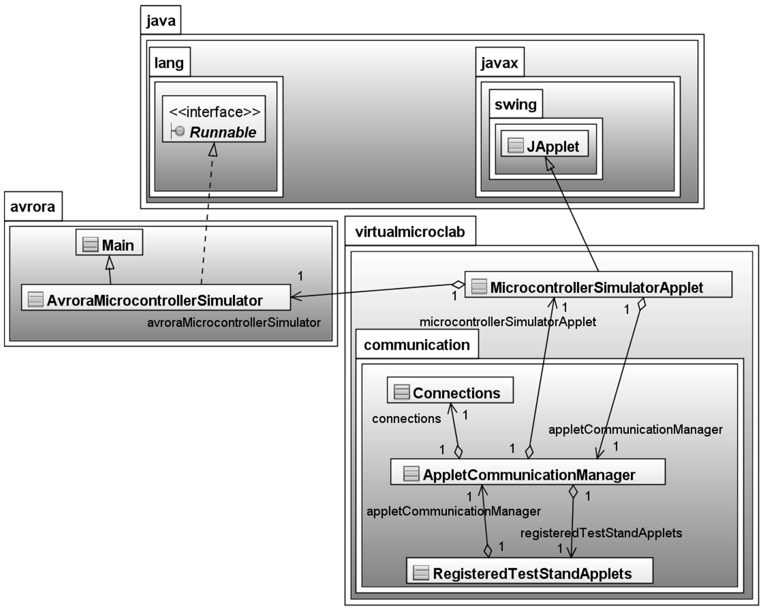

Figure 4.2.: General approach of a simulation device

4.4. Initial structure of the system and model

For a high cycles accuracy, the simulation has to trigger update events for each module connected to the controller in every simulation cycle. These methods need to be implemented for each module. They are included in an *abstract* class to facilitate the development process of modules.

LDL for configuration and high level of modularity

All changes and extensions to Avrora, such as running as an applet, are realized in a modular way to ensure a high level of integration of future *Avrora* versions into the VMCU. The modular concept can also be applied for all simulated peripherals (modules and devices) to enable their combination into more complex test stand scenarios. The modules can be combined by the user as necessary. The configuration is accordingly realized by building upon LDL (see Paper D and chapter 3). The description can be easily understood by all (both humans and machines). The configuration file can, for instance, be used for the pin connections between controller and modules and for the placing of graphical elements in the applets. The general idea of the LDL VMCU description file is presented in the Annex in section F on page 118ff.

4.5. Changes to Avrora system

As the main *Avrora* system was designed as a console based application (just for running simulations with parameters), some changes were necessary to use the system in a web-based environment. The changes were realized in a modular way by extending the project with new Java packages instead of directly changing in the Avrora source code to ensure lucidity and enabling integration into future versions of *Avrora*. To ensure intuitive use of the system, a GUI was researched and developed, enabling control of the states of the simulation (start, stop, reload). According to this, the simulation device was programmed as a stand-alone object, so the system is more flexible to handle.

Based on the platform concept of Avrora, which offers a comfortable integration of micro controller platforms, a system is now implemented which can load virtual hardware modules dynamically within the system initialization procedure. The connection data must be parsed from the LDL description file and it is used to generate the micro controller platform.

As the signal processing events are executed in every cycle, this behavior has to be also realized outside of the *Avrora* system, for each implemented virtual device / module. The fundamental simulation is realized in the *LegacyInterpreter*-class, which belongs to the *Java* package *avrora.arch.legacy*. Based on the monitoring concept there are several changes necessary to this class. In a self-written monitor the *fireBefore*- and *fireAfter*-methods of the *GlobalProbe* class override the standard behavior with custom functionality. This can be used for the synchronization mechanism, where in the *fireAfter* method the data processing methods of the simulated devices are invoked.

The presented simulation behavior as shown in fig. 4.3 is realized.

4.5.1. Interfaces / Virtualized pin connections

As a micro controller device utilizes input and output pins, these also have to be reflected in the software model. The *Avrora* system offers two interfaces to implement external pins to the simulator. These interfaces are shown in the *Microcontroller.java*-file in the *Java* package *avrora.sim.mcu*. The output interface requires implementation of the `public void write() (boolean level)`-method, as it is an output pin of the micro controller simulator. The input interface demands the implementation of `public boolean read()`-method, as it is in fact an input connection of the simulation device.

Drawn up in figure 4.4 the depth of inheritance is presented. The registration and connection of the defined pins in the VMCU can interact with the registered pins of an external device. In that way an explicit data exchange is not necessary. The final figure in this chapter, fig 4.5, illustrates the VMCU with three of the developed modules that are simulating the real hardware above. On the top there are two Robotic HomeLab kit UI boards and the Robot Arm RA1 Pro[2]. Below the virtualization engine, there are the reflecting, virtualized devices.

[2]The 'Robot Arm RA1 Pro' is produced by Arexx. More information: http://www.arexx.com/robot_arm/html/en/index.htm

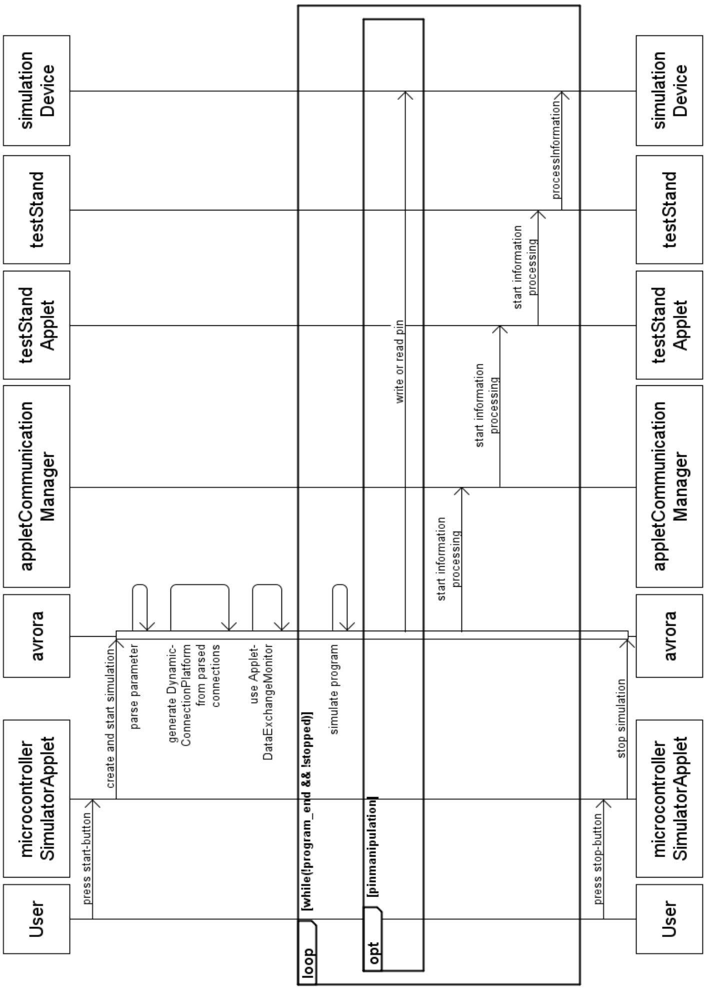

Figure 4.3.: Sequence diagram of VMCU use

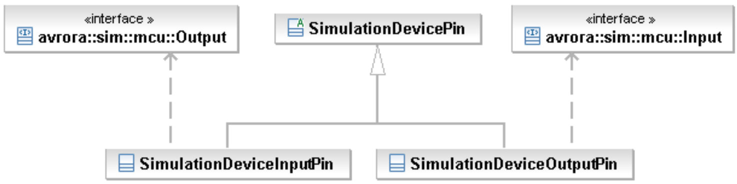

Figure 4.4.: Virtual pins of hardware module

4.6. Scientific originality of the VMCU

The first novelty of the VMCU is the unique approach for describing the interfacing of models by LDL. The second originality, not seen on the market before, is the VMCU environment which the simulated devices are placed in and accessible through. This environment can be used with any common Java-enabled web browser and the controller can be directly programmed online by utilizing invoked calls to a common *C* compiler that is available on the virtual lab server. This environment is enriched by an online *C* editor with Syntax highlighting and compiler feedback. It is the only combination of a virtual extensible system, equal to existing hardware, that is based on open source and freely available to anyone who wishes to extend it.

Figure 4.5.: Overview of Virtual Micro Controller Unit with three modules

5. Discussion

THE envisaged contributions of the present thesis are a comprehensive approach to a solution for the objectives, given in section 1.2, of sharing and mediating internet-accessible remote and virtual labs. The new items introduced and implemented were evaluated and proven with the different project partners mentioned in section 1.1.1, mainly those at Tallinn University of Technology and Bochum University of Applied Sciences.

Thesis discussion

Section 1.2 introduces the five over-spanning objectives to be solved in the doctoral thesis, that were covered in the subsequent chapters 2, 4 and 3, supplemented by appropriate publications. The publications presented in the Annex reflect this research and development. An overview of how the researched components fit together is illustrated in fig. 5.1. Three levels, 'Research', 'Development' and 'Proof of Concept', are presented with all the components described in this thesis shown in one of these levels.

Chapter 2 describes the "Holistic blended framework for Research and Education in Mechatronics and Computer Science", divided up into the *technical concept* (section 2.2) including the Robotic HomeLab kit, VMCU and Distance Lab and LDL and the *didactical concept*, ending with a discussion in section 2.4 about how the two concepts fit together. This chapter is completed by a state-of-the-art discussion (see section 2.1) of the application of eLearning in engineering education. In addition the concept is discussed in Paper A (p. 65) & Paper C (p. 92), with additional content in Paper E (p. 107).

The part about the VMCU introduces a novel concept in chapter 4, ranging from the VMCU framework to the overall concept with a focus on changes to the Avrora system (section 4.5) to enhance it to be a web-based virtual embedded system framework. Furthermore, the VMCU framework is covered by Paper B (p. 101) and also in Paper A.

The concepts of "Laboratory as a Service" and the "Lab Description Language" were covered in chapter 3, with a full state-of-the-art analysis about common ways of remote lab sharing in section 3.1, followed by an introduction to the LDL and LaaS approaches for mediating remote and virtual labs in section 3.3.

By giving the whole content of the thesis a unifying structure, the researched and implemented features can be classified into:

- **technical approaches**
  - Laboratory as a Service concept (LaaS)
  - Lab Description Language (LDL)
  - Virtual Micro Controller Unit (VMCU)
  - Robotic HomeLab kits
  - DistanceLab platform
- and **didactical approaches**
  - Teaching and learning material
  - Network of Excellence (NoE)

Objectives and solutions

Taking a closer look at the original intended objectives, these can now be compared with the solutions presented in the thesis.

(i) *to research a formal description language for the specification of remote and virtual labs in engineering science*

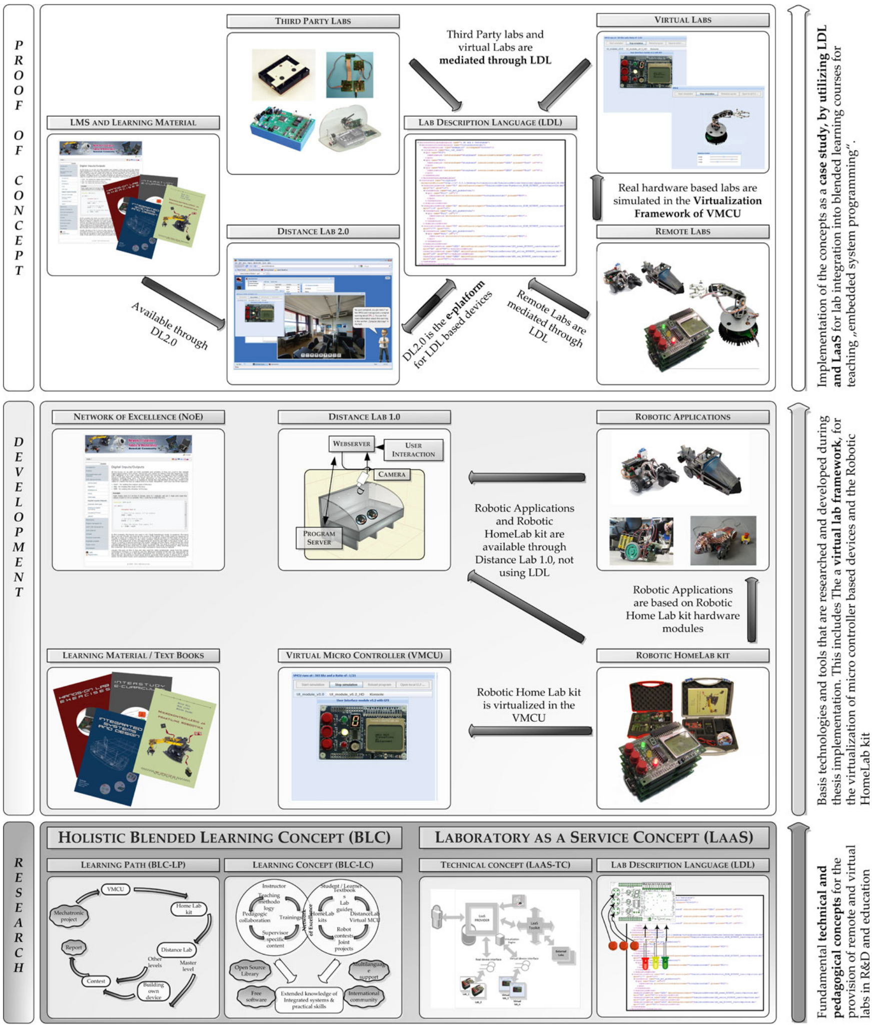

Figure 5.1.: Overview of thesis contribution

LDL as an XML dialect offers a proven and stable way for describing and mediating labs with a distance lab server. An implementation of LDL for embedded devices is utilized for the VMCU to describe virtual pin connections between controller and associated devices.

(ii) *to research a proper infrastructure for mediating internet-accessible labs and to identify and research necessary technologies and tools for interfacing and integrating remote and virtual labs into blended and distance learning processes*

The LaaS concept with LDL was submitted to the EC in January 2012 for an IP project and got positive feedback, being enabled for funding. Based upon LDL description the communication in LaaS is realized through web services based on WSDL and SOAP to interface with existing labs and control them, due to the small overhead produced. The LaaS toolkit offers an easy plug-and-play solution to integrate new labs to the LaaS Provider. The overall LaaS concept is a comprehensive solution for the envisaged cross-institutional lab sharing.

(iii) *to research and implement a framework concept for the creation of virtual embedded system devices,*

The VMCU offers a solid framework for virtual embedded systems. The virtual modules 'Robot Arm' and 'User Interface Board' are implemented applications which prove the concept. The VMCU is a web-based, modular framework using LDL and open source software.

(iv) *to research and develop a holistic blended learning concept by utilizing remote and virtual labs in education,*

The 'Holistic blended framework for Research and Education in Mechatronics and Computer Science' was researched and developed during several European projects and applied into daily education.

(v) *to implement and evaluate the researched technical framework, developing a proof-of-concept by utilizing virtual embedded devices and transferring this implementation to a real-world scenario, by connecting it to the blended learning concept*

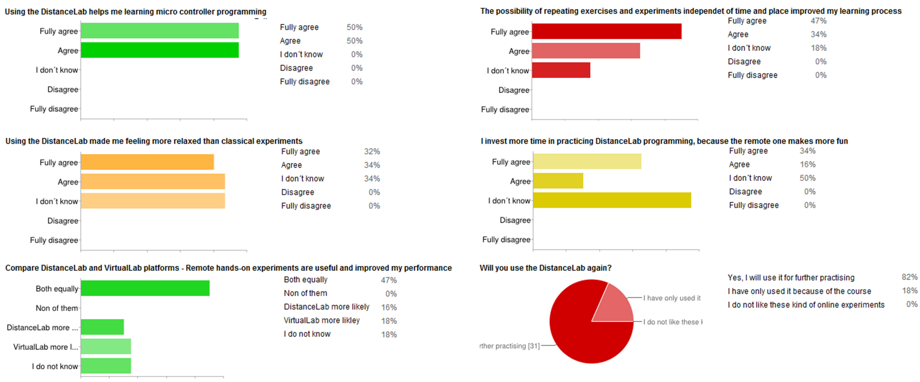

Figure 5.2.: Student feedback about BLC, VMCU and remote labs

This goal has been achieved in the frame of the European projects Interstudy, Autostudy, MoRobE, MCFuture, Netlab and ViReal[1].

Evaluation of the BLC

The BLC was implemented in Tallinn on a university level in the course "Microcontrollers and Practical Robotics" and is currently applied in Germany in a course called "Applied Computer Science". In the end of the Tallinn course, the students were asked to fill in a course feedback survey. The results are overall positive and above the average grading at the Mechatronic Institute in Tallinn.[2] In addition to general course feedback the students were asked to fill in a GoogleDocs online survey. This survey was composed more detailed to cover the real course content and the tools that were used during the semester.

[1]see section L, page 155 for further details about the projects.

[2]The following text is copied from a peer-review publication, covering a detailed evaluation of the BLC, VMCU and usage of remote labs, just accepted on 17.10.2012 for publication. This mentioned paper will be published in the "International Journal of Emerging Technologies in Learning (iJET)". The title for this publication is: "Embedded system and Robotic education in a blended learning environment utilizing remote and virtual labs in the cloud, accompanied by 'Robotic HomeLab kit'".

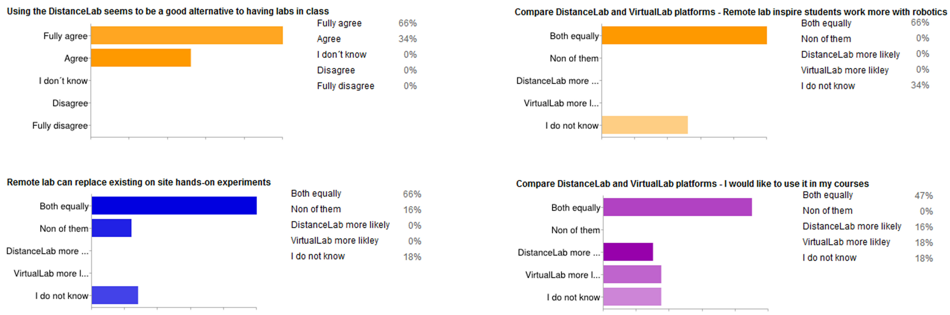

Figure 5.3.: Teacher feedback about BLC, VMCU and remote labs

The student overall feedback (n=46) is positive to all questions asked, as presented in the charts generated from the GoogleDocs survey in fig. 5.2, almost 82% state, that they like to use the DistanceLab again, even when the course is passed, while 47% ("Fully Agree") and 34% ("Agree") answered, that they see an improvement of their learning process due to being independent of time and place for their lab time. In addition (during a teachers training seminar) the tools were presented to local school teachers in Estonia and they were asked about their opinion about the utilization of DistanceLab, VirtualLab and HomeLab kit in K-12 education (n=38). This train-the-trainer seminar is held on demand, but several times a year in Estonia to educate teachers on how to use the HomeLab kit, VMCU and associated tools and on how to apply the learning concept in the daily education In total, during the seminar, 38 teachers from vocational schools in the Tallinn area were asked after they have been introduced to the tools that are belonging to the teaching concept and having two hours of working with them. Their feedback is presented in fig. 5.3. From their feedback DistanceLab, as well as VirtualLab (VMCU) could be a replacement for existing hands-on experimentations, as well as inspiring and engaging students in learning robotics. All of them are planning to use the tools in their K-12 courses, where 47% would like to use both, 16% the DistanceLab more likely, 18% VirtualLab more likely and another 18% that are unsure so far about the utilization of the concept. Comparable results were noticed amongst student groups in Germany and from feedback from project partners from the European projects.

6. Conclusion

Scientific originality

In the frame of this thesis, a holistic framework for remote and virtual labs ("Laboratory as a Service" (LaaS) and "Lab Description Language" (LDL)) and a associated blended learning concept ("Holistic blended framework for Research and Education in Mechatronics and Computer Science") were researched, devised and implemented. This research is accompanied by the implementation into a real-world scenario, including the "Virtual Micro Controller Unit" (VMCU) framework. As mentioned in section 1.1, the LaaS concept offers lab sharing for educational institutions, scientific research and digital factories. It was applied in first instance at an educational level as a proof of concept because of plainness issues. These approaches were initially introduced in section 1.1.1 and covered in the subsequent chapters. In this section the scientific originality of the researched solutions is investigated.

The scientific novelty of Laboratory as a Service (LaaS) is the **unifying and hierarchical approach of lab-sharing** without institutional borders by providing a LaaS Provider system for mediating and interfacing labs independent of their location. The second novel aspect of LaaS is the provision of **Lab Toolkits offering a plug-and-play method of connecting new labs through web services and standard interfaces**, enabling less experienced staff to integrate their existing labs via plug-and-play to LaaS. The third novelty is **the web service based concept** itself, as it **offers new open source technology approaches** for easy **integration of remote and virtual experimentations combined with associated learning material**. The fourth novelty is connected with the **structured collection and presen-**

tation of labs independent of their location, offering easy browsing and booking of them. This novelty enables, on the one hand, **easy access to expensive labs and equipment** for less endowed institutions; on the other hand it supports a **better degree of utilization of labs**, leading to a win-win situation for both parties involved. LaaS **significantly enhances the education of needier institutions through lab sharing**, by enabling them to benefit from expensive lab equipment existing elsewhere and not fully utilized. The LaaS concept **overturns the traditional coherence of practical work and presence at the institution**, by enabling lab attendance from home.

At a later stage the LaaS concept will be able to support an application in the frame of future factories, assisted by a 'rent a lab' system. This approach will help SMEs to hold steady through market challenges.

The scientific novelty of the Lab Description Language (LDL) is the **structured approach for describing labs and equipment** through a description language proposal including communication protocols for the integration of remote and virtual labs and their interfaces. This enables an easy integration of existing labs among different institutions by a common new vocabulary. A second novel feature is the **extensibility of the LDL approach**. This is realized by utilizing common web standards and applying XML Schema for the basic lab description, enabling other existing and newly developed schemas to be linked in. This holds great potential to evolve the solution to a common ontology for describing labs associated with, for instance, a GUI description (e.g. referring to MARIA[1] language). LDL is an institution cross-institutional concept for **mediating technical equipment** by a **common communication protocol**. For instance, the conceptualization **can be applied in the frame of 'Smart Factories'** for mediating and sharing industrial machines or other technical equipment through the internet. LaaS, together with LDL offers a set of tools and formal description for easy interfacing of technical equipment to the internet and mediating them through a communication protocol. These approaches **solve the problem of institution cross-institutional lab sharing**, enabling its application in the frame of future factories, as stated

[1]MARIA language for UI description - Additonal information can be found in [106]

in section 1.1. Both are following a "Service Oriented Laboratory Architecture", as suggested by authors in [27, 28, 35, 36, 37], **laying a basis for standardization in this field**.

The scientific novelty of the "Holistic blended framework for Research and Education" is the completeness of **covering all aspects of the research and educational process** by utilizing modern technical approaches. There is **no other complete concept** comparable to this available for Mechatronics and Computer Sciences. **BLC is the first concept utilizing LaaS and LDL for the lab integration** and is therefore an important proof of concept. The overall concept is accompanied by **freely accessible learning material and readymade learning situations** that can be presented to the class. Hosted by an international community, the **concept implementation and the associated material are available in several European languages**, enabling its application to be unlimited by language barriers. The learning concept can be applied to **four different educational levels**, high schools, vocational schools, university education and strongly industry bound in the form of life-long learning. Common solutions offer hardware kits or learning material or virtual hardware, and even a combination of them. This comprehensive concept offers a virtual hardware kit (the VMCU) as well as the Robotic HomeLab kit; and both work in the same way. It is a comprehensive approach, starting with utilizing the VMCU and continuing with the real hardware, up to complex robotic contests (depending on the students' abilities). In addition there is a forum and wiki system (called 'Network of Excellence') available to share experience in an international community.

The scientific novelty of the VMCU is the fact that it is a completely **web-based virtualization framework for embedded devices** where scientific controller based algorithms or educational based micro controller courses can be realized without the need for expensive real hardware components. The VMCU is the **first virtual lab utilizing LaaS and LDL** for the communication and mediation of extension modules. The next originality, not existing before, is the VMCU environment, which the simulated devices are placed in and accessible through. This environment **can be utilized with any common, Java-enabled web browser and the controller can be directly programmed online**. The VMCU platform is enriched by an online C-editor with syntax highlighting and compiler feedback. It is the **only combination of a virtual extensible system, equal to existing hardware, that is based on open source and freely available** to everyone who wishes to extend it.

Research conclusion and further outlook

As a long-term goal **Laboratory as a Service** and **Lab Description Language** will be proposed to the international community as a potential prototype universal standard for the specification and connection of remote and virtual labs and associated components. The consideration for adoption of such a draft idea by engineers, technologists and scientists will aid the longer-term success of lab sharing and encourage participations. In a possible prospective future version, a holistic soft- and hardware toolbox including documentation for automated plug and play distribution of remote labs can be built upon the general LDL and LaaS concept, mediating the XML formulation to real interaction and labs beyond the draft implementation in this thesis. This envisaged Lab Toolbox will be so easy to operate that a Lab Provider of distance labs will no longer need programming or advanced technical skills. Hardware integrations as well as the provision of ergonomic user interfaces should be handled by this toolbox. All lab related devices (labs themselves, intelligent tools, UI, LMS) can use LDL to communicate, as LDL is about the description and the protocol implementation of the overall system communication. This is delivered by a web service approach named Laboratory as a Service that is realized by components/software being developed to use LDL for communication, the universal approach for lab description and integration. LDL has the potential to streamline the creation of new labs and make many more labs available to the educational community engaged in the project. The meta-language is designed and built using existing standards to encompass all known requirements, whilst ensuring it can evolve over time to match technological developments.

The '**Holistic blended framework for Research and Education in Mechatronics and Computer Science**' will be developed further in the new project ViReal[2], for the field of 'Industrial Engineering', starting in November 2012. ViReal is an EU funded project, taking place in Estonia, Lithuania and Germany for implementing these thesis results to a marketable solution. The current concept, as all learning concepts do, will have to evolve over time to keep up with industry developments and be up-to-date.

The **Virtual Micro Controller Unit Framework** will be unfolded to the scientific community and made accessible to developers interested in building new virtual devices in summer 2013. The general idea of building new modules is offered in addition to students in Bochum as Bachelor thesis or practical work[3]
Drawing a final conclusion, all aims and objectives from section 1.2 could be solved within the frame of this thesis by taking care of all activities from section 1.3. The thesis author is eager to work further in the field of TEL, refining the concept for a wider application. The general approach of LaaS will be applied to the current project ViReal, as well as being implemented more profoundly.

[2]Virtual & Distance Labs environment for Industrial Engineering education

[3]A student at Bochum University of Applied Sciences needs to perform a ten week internship, that can also be carried out at university in the frame of being involved in research projects.

A. Comprehensive Blended Learning Concept for teaching Micro Controller technology utilising HomeLab kits and Remote Labs in a virtual web environment

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Comprehensive Blended Learning Concept for teaching Micro Controller technology utilising HomeLab kits and Remote Labs in a virtual web environment

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Abstract. This article introduces a comprehensive toolkit for the teaching of Mechatronics and Computer Science (especially micro controller technology and embedded programming). The approach is based upon a full set of materials, tools and products for internet-assisted distance learning. The concept presented here utilises remote labs, home labs and face-to-face teaching in classes. In detail, the learning concept is composed of a special DistanceLab solution, HomeLab kits and a Virtual Micro Controller Unit, assisted by supportive material which will be introduced in this paper and put into coherence with the didactic concept. Intended further steps in Remote Lab development are also presented by the authors.

Keywords: Virtual Micro Controller Unit, VMCU, Virtual Lab, Distance Lab, Remote Lab, Blended Learning, Learning Concept

1 Introduction

The teaching of Computer Science and Mechatronics has received a lot of attention in the last decade and its importance is still increasing. This seems to be a logical process as these fields have entered into everyday life and smart products spread more and more into homes. Most of these devices are mechatronic in their nature, which means they consist of software in addition to mechanical and electrical parts. Therefore, a good education in these fields, especially in microcontroller and embedded programming, is necessary to assure quality and a continuous advancement in the future. It is quite a challenge for educational institutions to keep up with the high pace of technological innovation in industry. The availability of (often expensive) ICT based learning material for learners, a lack of functional qualified teaching staff and insufficient space in classes for bulky equipment are the main problems identified in the frame of projects analysis of target sector needs[1].

The best way to fulfil the current and, more importantly, the future high demand for professionals in the fields mentioned above is to start at a quite early stage to delight young people with this technology. In the authors' opinion this can ensured by exploiting modern ICT based content, beginning in school and also covering vocational and university educational levels. Another point the projects were dealing with was to exploit modern Internet technology for education in these fields to make them more attractive for young engineers and keep them interested[2].

Within the following sections the different parts of the overall concept, which have been developed in the frame of joint EU projects [3–5] since 2007, are introduced and followed by detailed descriptions of each subpart where the concept was developed further [6] from one project to another. The current project *Virtual Academy Platform for Vocational Schools* (VAPVoS) [7], which will extend the whole framework by additional modules for the Virtual Micro Controller (VMCU) and integrate the results from former projects, has been accepted for funding.

2 Remote, Online, Virtual, Simulation and Distance Labs

In the literature, various terminologies are used for describing remote accessible or virtual online experiments. To avoid confusion this article discusses these terms before the principal section. The terms are used according to their definitions in [8–10], mainly taking the virtualisation component into account.

2.1 Distance Labs

A Distance Lab is a web platform offering any kind of online accessible experiment. This can be a remote or a virtual lab. These two kinds of labs are described next. In the case of the research consortium to which the authors belong, the term DistanceLab is used for a web platform including several labs accompanied by booking and user management modules.

2.2 Remote Labs

A remote lab (or online lab) enables actors (such as students or employees) to carry out experiments over the Internet which are normally performed in real-time physical studies in educational laboratories. Compared to a normal laboratory, additional equipment is needed to prepare traditional labs for online access. The fig. 1 illustrates these necessary changes. In a conventional laboratory environment, the actor uses the equipment with his or her own hands, getting direct feedback to any actions performed. When pressing a button the actor will see what the "reaction" of the lab is, without any delay. In a remote lab, the actor is connected by a personal computer (or any other device, like a smart phone or tablet pc) to the Internet. The actor is performing by utilising specific software or just by accessing a web application running in any common web

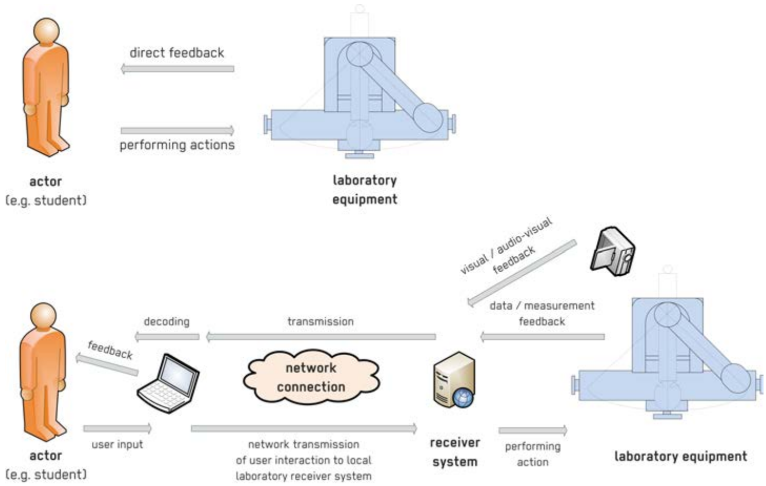

Fig. 1. A common vs. a remote laboratory

browser. The user's actions are transmitted to a receiver system (in most cases a computer system) with a public IP address. Naturally this receiver system is preceded by a user/laboratory management system, dealing with access rights and booking issues. This case is not illustrated here. The receiver system is directly connected to the laboratory equipment, enabling the actor to perform those standard actions to the hardware which are common for that specific kind of experiment.

Advantages of remote labs compared to traditional ones In a common lab course, mostly during practical work sessions as defined in the engineering curriculum, learners are encouraged to perform their exercises at a specific time, usually in a group of students, during the opening hours of their institution. There is often no consideration for disabled learners or for individual time constraints of the participants. Another problem is the availability of sufficient lab places. Especially, poor institutions may not offer costly experiments. Due to the nature of remote labs there is the possibility of sharing equipment, not only between students at the home institution but also between institutions themselves.

2.3 Virtual and Simulation Labs

The integration of virtual labs (see fig. 2) into a lab management system is generally easier than integrating remote hardware based labs. Some of the literature uses the terms "remote lab", "online lab", "cyber-enabled lab" and "virtual lab" synonymously but, while the first three are the same, "virtual lab" may not be used interchangeably. A virtual lab is a "laboratory" consisting of a specific piece of software. This software may be a proprietary one but also can be a web service or simulated hardware. The common case for all virtual labs is that real experiments are virtualised or simulated in this software, in most cases dealing with a challenge close to reality. A virtual lab can be accessed like a real hardware lab.

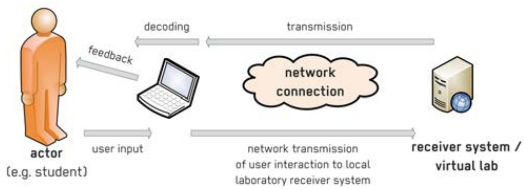

Fig. 2. A virtual or simulation laboratory

The actor is performing his actions from a distance by using an ordinary computer system sending his input over a network (in most cases involving Internet transmission) to a receiver system which will be in most cases linked directly to the virtual lab. In specific cases a virtual lab may involve different virtual machines (as in a network experiment, where students have to set-up a network infrastructure from a distance) or additional server systems (database systems among others) which are necessary for the virtual lab. The system itself directly sends the feedback over the communication channel back to the actor's personal computer. All computations are done in the virtual lab and only feedback to the user input is sent back.

Advantages and disadvantages of virtual labs Virtual labs have some advantages compared to real hardware labs. If the virtual lab is a software service then once the lab is set up it can be used by many students simultaneously, restricted only by the computational power of the host computer. It is also more robust than real equipment; a student cannot destroy the hardware whilst adjusting some settings or failures in programming. Another benefit is monetary. The system can be easily duplicated without paying additional costs. Of course, virtual labs also have disadvantages in comparison to real (remote) ones. A virtual lab can never perform exactly the same as real hardware in all cases. As it is impossible to include all environmental parameters in the virtualisation, a virtual lab will sometimes react differently to a real one. The best solution seems to be a combination of virtual and remote labs to get benefits from both of them. A general approach, also used in our consortium, is to use the virtual devices for basic education to teach basic system thinking and to get familiar with the hardware. In later steps the learners switch to real hardware.

3 Overview of the Blended Learning Concept

During the above-mentioned projects a consortium of European partners[3] developed a comprehensive concept for teaching microcontroller technology based on several results, drawn up in fig. 3, which will be described in separate sections in this article. The concept consists of the following parts:

- *DistanceLab* - The DistanceLab concept [11] was initially developed during the Interstudy project and developed further in the follow-up projects. In its current state it is a web platform for accessing real hardware (labs) and virtual labs which can be programmed or controlled directly over the Internet. The concept is being continuously developed further and currently applied into study processes in Estonia and Germany.

- *HomeLab kits* - These are cases with micro controller hardware, for the self-educating of learners at home or for utilising them in classes in the context of face-to-face education. The kits are combined with specific modules for different domains (e.g. Automotive or Mechatronic).

- *Virtual Microcontroller System* (VMCU) - A virtual version of the HomeLab kit hardware simulating the microcontroller's behaviour but acting like the real hardware.

- *Robotic Applications* - These applications are based on combined parts of the HomeLab kit. So, after teaching basics with the kits, it is possible to use more complex scenarios for further education and for inseminating the more interesting side of microcontroller programming in the form of robotics. These robots can be existing ones provided by the course supervisor or self-built by student teams. In the summer semester of 2011 this was run as a robotic competition in an Estonian undergraduate class.

- *Supporting Material* - The strength of the concept is the provided material in the form of a wiki based webpage, named Network of Excellence, where broad information about microcontroller programming and the basics of mechatronic principles is provided. In addition, corresponding hands-on material and teaching books were developed. The material incorporates practical examples, theory, exercises, questions, discussions and project examples.

All modules are integrated into one package as a microcontroller blended learning concept. The main idea of this concept is to integrate and emphasise e-learning

[3] Since 2007, the following partners were involved in the concept development: Tallinn Technical Unversity (Estonia) Bochum University Of Applied Sciences (Germany), Helsinki University of Technology (now Aalto University) (Finland), Kaunas University of Technology (Lithuania), Royal Institute of Technology (Sweden), Universit de Technologie de Belfort-Montbliard (UTBM), Estonian Qualification Authority and several SMEs and schools

Fig. 3. Blended Learning Concept overview

possibilities into the normal learning process (face-to-face and self-education at home as well as collaborative work over the internet in student teams) to create a successful symbiosis of all three worlds in the form of blended learning. As illustrated in fig. 3 the connection of three different approaches in teaching microcontroller technology are used. Initially, the concept was based only on the HomeLab kit hardware.

As part of the Interstudy project a web platform was developed to integrate HomeLab kit into an e-environment and to make the same hardware as formerly used offline in classes and labs accessible and programmable over the Internet. The next step, undertaken in project MoRobE, was to virtualise the microcontroller and all of its associated modules as a supplement to real physical tangible labs. From January 2011 onward, a stable version of this virtualised controller can be accessed by the DistanceLab.

The didactic link between the above-mentioned project results is demonstrated by the fact that most integrated labs in the DistanceLab are using HomeLab kit hardware components or are compatible to it (like VMCU). The mobile robot solution, for example, is completely realised by hardware from the kit. Therefore, it is possible to learn at home and have more expensive experiments (more motors and sensors in one lab) together with the distance aspect overview of the hardware, overview of the software, etc. in different languages.

In addition to this self-developed content, the consortium's approach was also to integrate further external labs into the DistanceLab. The application into the learning process and the course set-up [12] is not covered by this paper. The next sections introduce the tools and products utilised by the concept in more detail.

4 DistanceLab

4.1 The first version

The developed DistanceLab solution is intended for educational and professional use and was primarily developed in the context of life-long learning. It is composed of a Web 2.0 rich Internet platform, where different remote and virtual labs are integrated. In the first stage, the DistanceLab provided access to microcontroller based systems which can, but need not be, based upon the HomeLab kit hardware. In the current development stage external labs can also be integrated, so far as they can be interfaced using the consortium's defined standards.

The DistanceLab is designed for facilitating direct programming or controlling of the connected devices. In the case of programmable devices, this is realised by using a programming editor and an automatically invoked compiling process. This enables flashing programs directly to the connected devices over the internet. Some examples for interfaced labs are mobile robots, specific versions of HomeLab kits with add-on modules for a specific purpose (e.g. automotive study CAN-Module, LCD Display or a motor board) or the Virtual Micro Controller Unit with its various modules.

Fig. 4. Distance Lab Environment

In the case of real hardware labs, the user can access cameras showing the lab in real time to monitor the behaviour of the robot and can control the compiled program written by the user. The programming interfaces, together with the images of robot in different configurations, are shown in fig. 4. In the case of virtualised labs, the user sees the behaviour in a virtual world (like a 3D robot arm, or the emulated HomeLab modules).

4.2 DistanceLab 2.0

As the first approach is somewhat limited because of decisions about the technology, the consortium is currently working on an advanced approach. It is intended to integrate the DistanceLab and Network of Excellence as well as further material into a Webdesktop system, which will be app-based and so easily extended with new functionality. Current conceptualisation of this system is illustrated in fig. 5. The system will use the same technology base as the VMCU and, therefore, our current results can be integrated in a convenient way. We intend to extend the Webdesktop system with new applications such as a virtual companion (the avatar in the lower right corner of fig. 5) based on knowledge assessment techniques which will provide useful hints for the users based on acquired information from the Network of Excellence and semantic analysis. It is the long-term goal to provide a virtual adaption of all real hardware labs. Using this approach, the first steps in a new lab can be undertaken in the virtual version and then, as soon as the course instructor is satisfied with the student's learning outcome, change to using real hardware.

5 HomeLab kits

The Robotic HomeLab kit (see fig. 6) was developed by the consortium with the participation of both authors. It is a mobile, ready to use small test stand packed

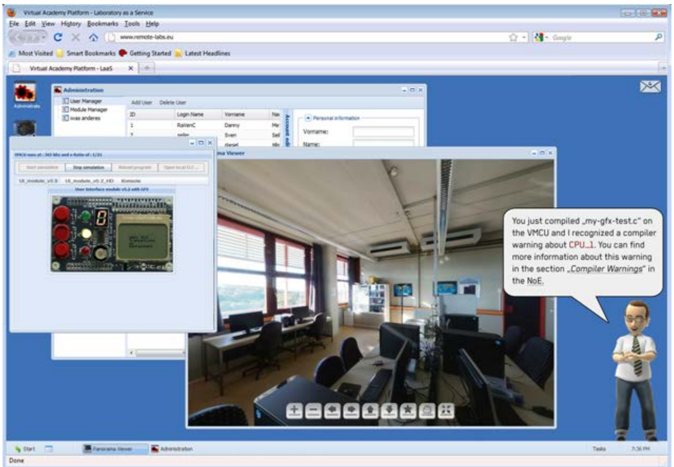

Fig. 5. Distance Lab 2.0 concept

Fig. 6. HomeLab kits

into a case. It can be connected to a PC and operated in computer class, at home or in the workplace. The purpose of the kit is to provide practical and effective hands-on training. Students may combine various solutions with different levels of complexity and functionality, based on the modules belonging to the kit. The main feature of HomeLab kit is its mobility - the case is a small and compact box and all modules with the necessary tools are housed in that. Taking the current development status into account, the HomeLab kit offers, for example, hardware and exercises for 7-segment LED display, LCD (alphanumeric as well as a graphical one), sensors (potentiometer, infrared, ultrasonic, etc.), different motors (DC, servo, stepper), as well as a networking module (for Bluetooth, Ethernet and ZigBee), a CAN module and USB for direct connection to a PC (for example a student home computer). Simple and easy to install software is used to connect the main controller to the computer. This is particularly important because the student can start practical experiments in school and then continue with self-learning at home or even in the workplace.

The HomeLab kit is supplemented by a specific software library, enabling easy access to the modules and their functionality which is available as open source for all users. More experienced users may abandon using it but for beginners using the library makes it a lot easier to start with micro controller programming. This library is extended by implementing new modules or labs, so it can be used even for devices not consisting of HomeLab kit hardware, so long as they are micro controller based.

In detail the following kits are available:

5.1 HomeLab Basic kit

This basic kit features an *AVR ATmega2561 Development Board*, including Ethernet, SD card reader and integrated JTAG programmer. In addition the *User Interface Board*, composed of buttons, LEDs, Graphical LCD, 7-segment indicator is integrated to this kit.

In addition to the Controller and User Interface module, the kit consists of a multimeter for the basic measurements, a power supply and a USB cable. All needed software for Windows and Linux operating systems are included together with practical examples and different types of guides. The latest addition to the kit is a live Linux USB stick which has a preconfigured IDE and can be used in any computer able to boot from USB without affecting the main system. This is especially useful in cases where the kit is used in public computers, e.g. in a library. With the HomeLab Basic kit many exercises can be performed and this kit is usually enough for the introductory courses. For more advanced courses, such as Robotics or Embedded systems, the HomeLab Add-On kit may be necessary.

5.2 Sensor and Motor Add-On kit

This add-on kit consists of a *Sensor module*, *Motor Module* and a *Communication Module.* The Robotic HomeLab Add-On kit provides the most common functionalities in robotics, which are sensing, actuating and communicating. Different types of this functionality can be studied and tested with the Add-On kit. The Add-On kit requires the HomeLab Basic kit as the main micro controller is included in the Basic kit but not in the Add-On kit. Also, the User Interface module is often needed when working with sensors, motors and communications. Together with the Basic kit this is a perfect set of hardware tools for many different practical courses, like Mechatronics, Embedded systems, Robotics, Practical Programming, Automation, among others.

The sensor module is equipped with an analogous sensor and low-pass filter combined board with on-board sensors (temperature sensor, light intensity sensor, potentiometer and mic), an ultrasonic distance sensor and an infrared distance sensor.

The Motor Module features DC motor (with gear and encoder), RC servo motor, Stepper motor (bipolar or unipolar stepper) and with an *motor driver board.*

The communication module module is based on a communication board, with 2xRS232 and a ZigBee or Bluetooth wireless unit.

5.3 HomeLab additional modules

Additional modules are not packed into the cases but can be directly connected with HomeLab Communication module. Practical examples and exercises are provided for these modules. For instance, the following add-on modules are available.

RFID module , offering a high frequency RFID reader with several different RFID tags.

Machine Vision Module , a camera which can be used with CMUcam3[13], the Open Source Programmable Embedded Color Vision Platform.

6 Virtual Labs

6.1 Virtual Microcontroller System

The Virtual Microcontroller System (VMCU)[14] is the newest innovative result embedded into the blended learning concept. It is based on Avrora [15, 16] with an Ext GWT [17] based GUI. It is a fully functional, but virtual, microcontroller running in any modern web browser[4], with JavaScript enabled, supporting the

[4] Consortium tested so far: Chrome starting with version 11; FireFox starting with version 3; Internet Explorer starting with version 8

latest Java version (at least build 1.6.0.x). It can be used for educational purposes, as well as for prototyping. The system is illustrated in fig. 7 in the lower left corner, showing a virtualised LCD display and the Studyboard developed during the Interstudy project. The picture also shows the real hardware the VMCU is based upon, in the upper left corner.

Fig. 7. Virtual Microcontroller System and Virtual Robot Arm Lab

The VMCU is a valuable and useful extension of the concept. Its main use is the education of beginners in micro controller programming but in fact it is possible to use it for any task that could be undertaken with the HomeLab kit basic modules. Compared to real hardware, it is easy to set up new instances of the VMCU without any extra costs (except server capacity). Many students may use the virtual solution, without any need to buy more expensive hardware for all workstations.

Currently, the following add-on modules are available for the VMCU unit:

- User Interface Module version 3.0
- User Interface Module version 5.2 with a Graphical display
- User Interface Module version 5.2 with an attached LCD display.
- 7-Segment-Display Module
- GFX Display Module
- LCD Display Module

All User Interface modules feature a 7-segment-display, three buttons and three different-coloured LEDs, which enables working with the system for several weeks at tertiary level, or for half an year on lower educational levels[19, 18]. The VMCU is embedded in a website, developed by utilising Ext JS 4[20] to build a fully dynamic Ajax-enabled web platform, as illustrated in fig. 8. The platform features an integrated development environment (IDE) a user can use for directly programming online. This JavaScript editor offers all necessary functionality (1), like *Select Files* (for loading files), *Save File* or *Save & Compile* what is needed for programming embedded devices, such as the VMCU. There was also a console feedback implemented (3), to give the user feedback when any errors occurred in the compiling process. Such errors are even highlighted in the editor, as is expected by users of an offline IDE. Each user has his/her own directory to store source code in (4). These are stored in the section *User Files*. To enhance working with the virtual controller, the course-supervisor can upload additional files, which will show up in the section *Example Files*. These files can only be loaded into the editor and saved to a new name, but not overwritten. So a supervisor may add hints or exercise solutions for the students.

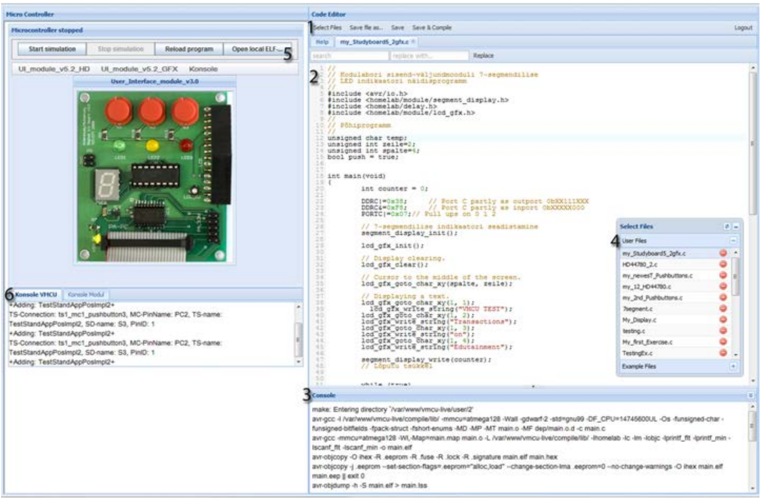

Fig. 8. Overview of VMCU environment

The system also allows binary files to be loaded into the virtual controller (5), so any additional development environment may be used for development. As the Virtual Micro Controller Unit behaves like real hardware, it makes no difference.

Another goal we track was to make the internal behaviour of the micro controller or embedded system more transparent to the user. Therefore, we included a console output of the internal performance of the controller so it is easy to see which pins are connected and how they are addressed. Currently, new modules and extensions are being developed for the VMCU. In a version which will be complete in the near future there will be a *Physics Engine* implemented for the whole system, available for Virtual Lab users. This engine can be connected to virtual sensors, which are themselves interfaced to the VMCU. Currently, a PTC and a NTC sensor for temperature measuring are in test status. The data these sensors are reading are passed forward from the Physics Engine, which can simulate natural environmental values, like air pressure, humidity and light intensity amongst others. These data may be set up as values over time, or following a function over time. The general idea is to build a robotic 3D simulation environment based on the Virtual HomeLab kit hardware (for instance a moving robot) but with simulated environmental physical values in addition.

6.2 Virtual Robot Arm Lab

In addition, as illustrated on the right side of fig. 7 two Robot Arm Labs are currently in development. While the hardware robot arm (upper right corner) is already available online, the virtual version is currently being tested in-house before it is made publicly accessible in the DistanceLab. This lab also makes use of the VMCU technology approach. With this robot arm lab, students can train in real-life situations like *picking and deposit of pieces* or *swiveling*. It is not a substitute for working with professional robot devices and it is not intended to be. From the consortium's point of view, it is the right choice to introduce machine control to learners. When the virtual robot arm version is fully functional, the next step is to simulate the behaviour of real industry robot arms, followed by more complex devices.

7 Supporting Material

There are different kinds of supporting material currently in existence:

1. Network of Excellence (NoE) [21]
2. Hands-on-lab exercise book [22]
3. Learning situations for vocational education [18]
4. Textbook "Microcontroller & Mobile Robotics" [23]
5. Textbook "Integrated Systems & Design" [24], as a result of project Interstudy, covering current issues in Mechatronics. This book will not be described further in this paper.

7.1 Network of Excellence

The *Network of Excellence* consists of a forum for discussions and an encompassing wiki page. These collaborative tools have to be seen as the main educational material. The wiki page is a supportive environment for students and teachers using the Robotic HomeLab kit. Participating partners offer learning materials and a full set of methodologies for the teaching and self-education of AVR microcontroller technology (which the HomeLab kit consists of). Additionally, information about the ARM-CAN HomeLab kit or AVR-CAN kit can also be found there.

The page offers a versatile set of practical examples about e.g. digital input/output, indicators and displays, sensors and motor control. Additionally, the website has a special section for teachers which includes teacher training material and, most importantly, the exercise solutions and answers to revision questions. In the Robotic HomeLab Community the consortium intends to make all learning material and also the teaching methodologies directly accessible for interested learners and teachers, as well as ready-made examples about teaching courses for vocational schools to apply the developed solutions directly in school, which is the main strength of our approach. The overall page is designed as a multi-language website, with current translations to English, Estonian, German, French and Lithuanian, with English as the base language for all further translations. The next intended languages are Turkish and Russian. The strength of this website is the number of supporting teaching aids provided by teachers and developers in different European countries and, therefore, the influence of various cultures, level of knowledge or styles of teaching which leads to a (nearly) complete set of material.

7.2 Other material

Learning situations During project MoRobE [5] a full didactic concept of the learning situation with full methodology was developed. This learning situation makes use of the HomeLabs as well as VMCU and integrates them in a real-world scenario of an injection moulding facility, where the HomeLab kit controller board with interfaces add-ons monitors the system behaviour.

"Microcontroller & Mobile Robotics" Based on content of the NoE a new textbook ("Microcontroller & Mobile Robotics" [23]) was provided to support students and self-learners in keeping their motivation to learn. The textbook is built with references to those fundamentals necessary to understand the topic discussed in a specific chapter. So a student may directly start with the chapter on writing to the LCD display, looking up necessary background information from other parts of the book. Currently, this textbook is available in Estonian and English. A German version will be published soon.

8 Robotic Applications

The whole concept designed as illustrated in fig. 3 intends to use the same hardware for even more complex programming tasks, like a moving robot. Building on the HomeLab kit hardware, the consortium developed robots using only modules which belong to other material we provide. Thus, students can train on the VMCU, after using specific modules from the HomeLab kit leading to complex programming, by including several modules attached to the micro controller. A prototype concept of the robots used in our concept is shown in fig. 9.

9 Conclusion

The paper has introduced all parts of the blended learning concept and gave a comprehensive overview about the project results of the latest European projects

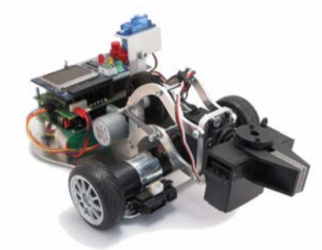

Fig. 9. Robotic Application

carried out by the research project consortium. Currently, project MoRobE has ended and we are starting a new project in a similar field working on enhancing the education of embedded systems. For further research, the consortium is currently planning to research and develop an open, standardised interface to easily plug-and-play remote laboratories into the educational process. This purpose should be realised by formulating a new architecture called "Laboratory as a Service" (LaaS), which will establish a generic method to integrate existing experiments and laboratories using a semantic description of devices and/or labs. This method also includes the research of user interfaces for the specific pedagogical contexts of our target groups, mediating the complexities of creation and usability of distance experiments. The concept includes developing virtual labs so students may gain knowledge of interactive experiments (virtual ones) before heading over to the real hardware. Of course this will be only carried out for a limited subset of labs.

The labs should be capable of being used on any target platform or medium (like mobile devices) supporting the new open standard. In addition to this research it is planned to interface widely-used e-learning platforms, like Moodle or Blackboard. On one hand it is intended to create the above-mentioned open standard which enables the integration of labs into any kind of "product" (e.g. mobile devices, any kind of software and websites); on the other hand there is also a need for one common platform which integrates all developed products. Thus, the generic platform for this project will be a wide-scale web platform, behaving like an ordinary Desktop system, but running in any modern web browser. This approach is similar to the one illustrated in fig. 5 but more advanced. This platform has to be seen as the over-spanning tool to access labs and also other included learning tools. In addition the platform is intended to be used for Europe-wide lab sharing between partner institutions offering, for example, a comprehensive booking system and user management for large-scale networks.

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B. Holistic web-based Virtual Micro Controller Framework for research and education

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Holistic web-based Virtual Micro Controller Framework for research and education

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***Abstract*—Education in the field of embedded system programming became an even more important aspect in the qualification of young engineers during the last decade. This development is accompanied by a rapidly increasing complexity of the software environments used with such devices. Therefore a qualified and solid teaching methodology is necessary, accompanied by industry driven technological innovation with an emphasis on programming. As part of three European projects regarding lifelong-learning a comprehensive blended learning concept for teaching embedded systems and robotics was developed by paper authors. It comprises basic exercises in micro controller programming up to high-level student robotic challenges. These implemented measures are supported by a distance learning environment. The programming of embedded systems and microcontroller technology has to be seen as the precursor for more complex robotic systems in this context, but with a high importance for later successfully working with the technology for further professional utilization with these technologies. Current paper introduces the most novel part; the online accessible Virtual Micro Controller Platform (VMCU) and its underlying simulation framework platform. This approach conquers the major existing problems in engineering education: outdated hardware and limited lab times. This paper answers the question about advantages of using virtual hardware in an educational environment.**

***Index Terms*— Distance learning, Computer science education, Remote systems, Robotics, framework, virtual micro controller**

I. INTRODUCTION

Embedded system and microcontroller field received a lot of attention over the last years and their importance is still increasing. This seems to be a logical process as embedded devices themselves have entered into everyday life, where smart products are already widely spread in many homes. Most contemporary electronic devices at home and in industry are embedded devices by their nature. This means, they consist of software in addition to mechanics and electronics, controlling the device behavior and offering functionality. The software aspect to this is continuously growing [1] in modern products. The programming of such devices, particularly in relation to conventional computer programming methods, is becoming more common. Due to the fact that almost every modern machine consists of embedded devices there is a high need to educate more people to design, develop and maintain these kinds of systems [2] on a professional level. One problem in microcontroller education is that (often) special hardware is required, which is (in total costs) quite expensive for laboratories. Also the risk of them being destroyed by microcontroller beginners is quite high (over-voltage, wrong fuses amongst others). These issues led to the approach of developing an educational concept to counter the gap between rapid developments in technology and the state of knowledge of young engineers [3].

Since 2007 new conceptual blended learning solution is developed which have resulted a complete set of embedded hardware, named Robotic HomeLab kit, remote access to this hardware, named DistanceLab and virtualized microcontroller unit with virtualized peripheral electrical components, named Virtual Micro Controller (VMCU). All solutions are accompanied by several add-on modules for different engineering sectors (for instance Electrical Engineering, Automotive and Mechatronics). The solution is supported by Blended Robotic Teaching & Learning Concept [4, 5], completed by ready-to-use pedagogical material, distance access to hardware, and miscellaneous hands-on online learning material.

The integration of virtualized and remote laboratory solutions into the classical teaching processes within the fields of mechatronics, electronics and computer science became a major topic within the scientific community and among major stakeholders. The most important reasons for this development are the constant innovations in technology which make it quite hard for educational institutions to keep their lab equipment up to date. The application of distance lab technology raises also the mobility of students as well as the accessibility of lab equipment for students abroad, special needs learners or people in lifelong learning who have very limited access to classical lab.

To cover a full approach suitable for implementation into the educational routine, more than just pure technology is required. Our goal is to provide a concept to link the classical approach with distance education concepts and technology. To reach this goal, the VMCU and virtual hardware framework presented in this paper will be based on the existing real hardware components that are already established in education. Main strength of the concept is, that the learning material provided for the lab work will be exactly the same for real or distance labs. In the daily teaching process, virtualized and remote labs will become an auxiliary tool but will never fully replace hand on lab experience. The virtualized microcontroller must be seen as a supporting technology in this development. The didactical materials are set to cover a full approach utilizing all technologies (remote-, distance- and real labs).

Latest development in this modular and extendible concept and main focus of this paper, which technical part is illustrated in Figure 1, is a fully virtualized microcontroller system, named Virtual Micro Controller Unit (VMCU) and virtualized pin connections with external electronic components. The next section will pick up on the VMCU environment and its applications, concluding with further development prospects. In the third section, "Lab Description Language" (LDL), a dynamic approach for describing and mediating remote and virtual labs is introduced, followed by a section about the VirtualLab Environment. The last section shortly illustrates the virtual solution counterpart – a DistanceLab platform and describes the concept of concurrent use of both platforms.

II. VIRTUAL MICRO CONTROLLER UNIT

The newest part of authors blended learning concept [4, 5, 6] is the so named Virtual Micro Controller (VMCU) [7, 8], which is patterned on the Robotic HomeLab kit [9] hardware. It is a fully featured, but simulated web environment behaving like real hardware. VMCU is based on Avrora framework [10, 11] and Java programming language. It can be used for prototyping and research experiment as well as for educational purposes. The Robotic HomeLab kit, the robots as well as the VMCU are accessible over a web portal, called DistanceLab.

It interfaces remote laboratories and virtual experimentations that can be programmed and observed over the Internet. The system works with camera feedback. In addition to the hardware, the concept is offering additional material, with a lot of exercises for the real hardware and also for the VMCU.

The idea of the concept is to utilize the VMCU in the beginning of educating microcontroller technology or for self-studies at home, as only a modern web browser with Java enabled is needed to access the virtual hardware.

A. Design Conditions

For satisfying all needs to build products for an educational environment and reaching the desired high level of attractiveness to fascinate young people for this technology, it is important for the system design to rest on web technology. Therefore the available tools appropriate for the development are limited.

First requirement formulated by the authors was to research a system based on modern Internet technology, running as a single web platform, accessible by any common web browser. Second condition was having the VMCU to work with binary files, so common C programming language development software can be interfaced to the VMCU environment. Author's third framework condition concerns the cost of the system. The intention was to minimize costs as much as possible, without any annual/recurring fees, to encourage its acceptance. Forth requirement is about the demonstration purposes. For attractiveness reasons a graphical version of the controller is necessary; textual output only will not be sufficient. As fifth condition the general behavior of the VMCU environment should be comparable to real hardware belonging to the Robotic HomeLab kit. The last requirement is to enable the VMCU being included into the DistanceLab environment.

B. Interface / Inter-Connectivity concept

To create a microcontroller test stand, different environmental values and hardware components have to be taken into account. The main part is the microcontroller chip itself, as this chip deals with nearly all operations of a test stand. The deep state-of-the-art research prior to the VMCU development (described in detail in [10]) resulted, that Avrora framework is the best base micro controller simulation solution for given task, as it is Java based and freely available as Open Source, which fits the demands for developing it further in a modern web environment.

As the initial structure of the system and model is based on the Avrora framework the programming language Java was chosen, too. Because of this and the modular structure of Avrora, which is separated into Java-packages, the creation of a new Java-package known as *virtualmicroclab* was the base for further development. Due to the condition that the VMCU should be based on Web 2.0 technology, applets and an inter-applet communication schema for component interconnection was the appropriate way to design the overall system.

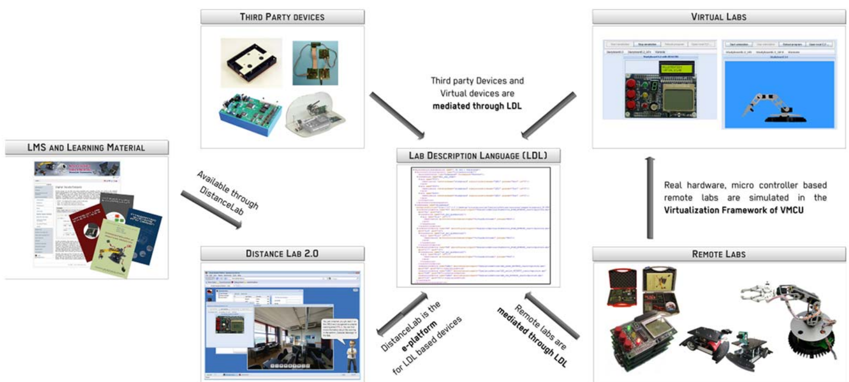

Fig. 1 – The VMCU in the full concept

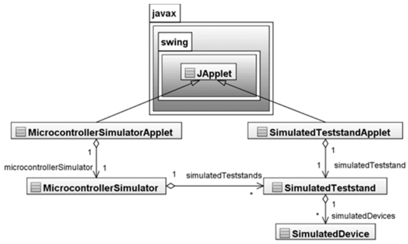

Fig. 2 – General VMCU System design

The general system design is shown up in Figure 2. For high accuracy, each module connected to the controller handles an event in every cycle of the simulation. These events have to be implemented for each simulated hardware component. Therefore they are included as an abstract definition implementation in the interface of each device.

III. LAB DESCRIPTION LANGUAGE (LDL) FOR CONFIGURATION

All changes and extensions to Avrora, like running as an Applet are realized in a modular way to ensure a high level of integration of possible future Avrora versions into the VMCU Environment. The modular concept needs to be applied for all additional components (modules and devices) to enable their integration into more complex test stand scenarios.

Due to standardized interfaces, these modules can be combined by the user as necessary. The configuration is realized by utilizing a new description language for lab integration, called Lab Description Language (LDL) developed by the authors and presented in figure 3. LDL is based on the XML standard resting upon ontology for remote labs. So it can be easily understood by humans and machines. The configuration file is mainly used for the interconnection between virtual components like the controller or simulation modules. The arrangement of the user interfaces and graphical elements with the frontend solution are also defined in LDL. Lab Description Language allows transparent access to laboratories independent of the type of the system, because LDL allows labs/experiments to be defined in an abstract manner. LDL is similar to the RDF-based Lab2Go Description Model [12] or the LiLa Ontology [13]. While the Lab2Go approach and the Lila Ontology are focusing on easy integration of laboratories and their associated experiments, LDL is additionally able to describe components used in virtual experiments in detail. For instance, LDL in its current state holds an ontology for embedded system related electronic parts that can be virtually connected to the VMCU. The LDL approach is capable of mediating dynamically tailored experiments. For instance, a teacher may create a new VMCU module by just adding components like buttons and LEDs and virtually plug them together and share this new experiment with her/his class. Most important benefit of this approach is that a "lab creator" does not need neither advanced programming skills nor deep knowledge in electronics for creating new experiments.

LDL is meant as a potential prototype of a universal approach for specification and connection of remote and virtual labs and associated components. The consideration for adoption of such a draft idea by engineers, technologists and scientists will aid the long-term success of the networked labs and encourage participations. LDL provides the ontological basis to develop a web-based platform incorporating a comprehensive toolbox of components, component interfaces and access interfaces. The standardization of required interfaces and the development and free distribution of software components for lab integration and distribution solves the major problems of Internet accessible labs.

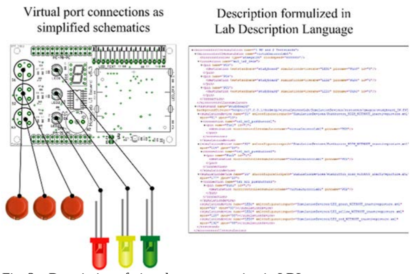

Fig. 3 – Description of virtual port connection in LDL

LDL will allow transparent access to laboratories independent of the type of the system. LDL allows labs/experiments to be defined in an abstract manner, all objects needed to integrate existing Labs (button, editor, widget, interface to software tools, e.g., Matlab), which can represent different laboratory components, will be defined in LDL in terms of tags and attributes based on OWL2.

For instance a description of the green LED looks like the following LDL in fig. 4.

```
<simulationdevice type="LED"
                  classfile="virtualmicroclab.simdev.led.LED">
<parameters>
  <parameter name="color" type="String" value="green" />
  <parameter name="connection information" type="String"
             value="add your device description here." />
</parameters>
<resources>
  <resource name="activePicture" type="image"
            path="components/electrical/LED/Green" />
  <resource name="inactivePicture" type="image"
            path=" components/electrical/LED/Transparent />
</resources>
<inputpins>
  <pin name="Pin0" id="0" />
</inputpins>
</simulationdevice>
```

Fig. 4 – LDL description example

LDL in its current state can be utilized to describe the interconnection of micro controller based devices, their interfacing to remote lab platforms, such as DistanceLab. In addition LDL offers a comprehensive way to describe and mediate the interfaces of external labs to be included into a DistanceLab environment.

A. Interface / Virtualized hardware inter-connections

For a microcontroller based simulation framework the abstraction and simulation of electrical signals and connection is a crucial part for the usability and extendibility of the whole approach.

As a microcontroller device uses input and output pins, they must be reflected in the software model. The Avrora system offers two interfaces to integrate external signals to the simulator. These interfaces define methods necessary for all external communication of the controller with the simulated environment. The output interfaces of the virtual controller require the implementation of certain events. These events are using for instance *read* and *write* methods and are very similar to common unbuffered I/O concepts. In Figure 5 the depth of the inheritance is presented. After the registration and connection of external device pins to the VMCU pins, they can interact without the need of explicit data exchange.

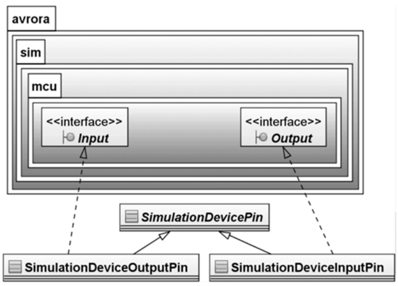

Fig. 5 – Virtualized I/O concept

B. Communication in VirtualLab

The whole solution is a web browser based distributed system. Due to the utilized web technologies (HTML5) it is also run capable on modern java-enabled smart phones or tablet PCs. Various software components, developed by project partner institutions will operate in the same environment loosely connected to each other. The concept by itself sets very high requirements to the underlying communication engine. The challenge of real time embedded device simulation requires the system to grand very short response times. For some applications like sensor systems or communications it is important to have response times in the milliseconds scale. Within a single monolithic software solution this requirement would not be too hard to fulfill. Considering a distributed web based solution, where all components are programmed by different developers hosted on different servers, the real time and communication requirements turn into a crucial challenge for the system design.

The concept chosen to mediate this problem was the browser based inter-applet communication. In this concept the browser serves as host application and also as an arbiter between all components of the distributed system. The connection between all different simulation components like sensors, actors, visualization modules and the controller itself are defined by the LDL system model. As a part of the communication concept the conjunctions between the software components must be realized according the overall simulation model definition. In a final step the java representation of the virtual components are connected for inter-applet communication. To realize inter-applet communication, the applets have to be registered to each other. Based on this fact, the names of the desired parameters of the simulation device and the Test Stand applet are equal to the pin connection in the LDL configuration of each virtual test stand. The *TestStand* applet is able to search for an applet with the unique name of the microcontroller simulation device it is intended to connect with. Once found, the registration process is realized as shown in fig. 6. Another important component of the communication concept is the Communication Manager Applet. It serves as an arbiter to gain a lucid structure. Furthermore, this arbiter is able to handle the cyclic events to update the connected simulated components. As the Communication Manager object is registered with a certain components applet, a mutual invoke of method calls is possible, as the applets are running in the same Java Virtual Machine. After successfully linking the applets and the parsing of the LDL definition, the user interface components and other parts, like simulated devices, the simulation can be started.

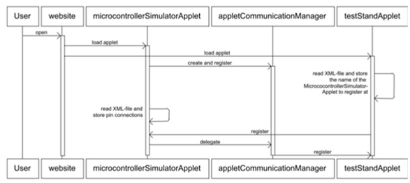

Fig. 6 – Sequence diagram of Communication manager

While starting, a cyclic event named *"processInformation"* is invoked by the Virtual Micro Controller.

C. Improvements of the Avrora system

As the original system was designed as a console based application, several improvements were necessary to use the system in a web environment. The improvements were realized following a modular concept, fitting into new Java packages and not directly in the Avrora source code to ensure lucidity and enabling easy integration of future software versions and further development into the framework. To ensure intuitive usage of the system, a Graphical User Interface (GUI) was developed, enabling control of the states of the simulation (start, stop, reload). Based on the platform concept, which offers a comfortable functionality to group microcontrollers and statically connected periphery devices to a platform, like the MicaZ mote[14] or instance, a loader has to be implemented, which is able to load virtual hardware modules dynamically into the system´s initialization procedure.

This new platform is called *"Dynamic Connection Platform"*. The necessary connection data is obtained from a corresponding LDL system model and used to generate the simulation environment. As the signal processing events have to be invoked in every cycle, their behavior has to be implemented outside the core system in each simulated device.

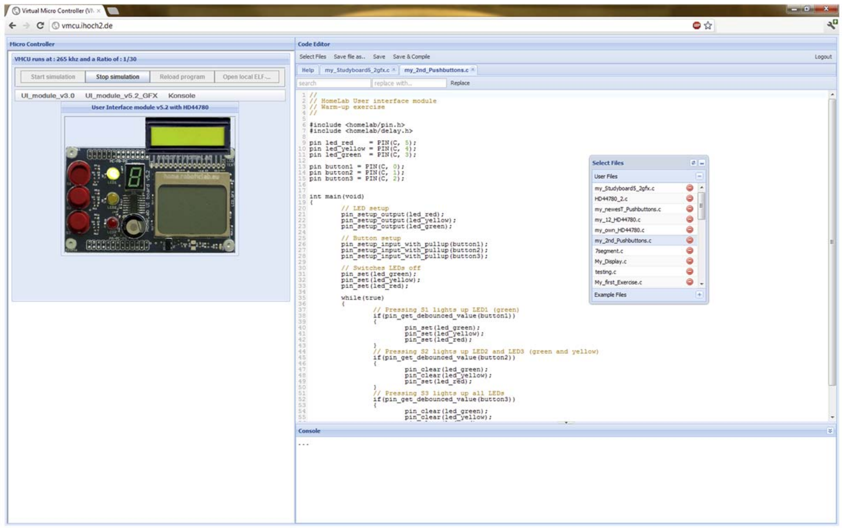

Fig. 7 – Virtual Lab Framework Platform, showing VMCU

IV. THE VMCU PLATFORM

The whole VMCU unit is integrated into a web environment (accessible free for use at [7]), using the ExtJS JavaScript framework and {}CodeMirror, as shown in Figure 7. The login is possible (after registration) for everyone interested, or by using Bochum University LDAP login. In the figure, the VMCU GUI is shown on the left and on the right the programming area is illustrated. The GUI offers a comprehensive development environment for the VMCU, including syntax highlighting, feedback about the compilation process and demonstration exercises, which are loaded into each new user profile. Strength of the system can be seen in the (almost) independence to operation systems, as only a few hard- and software conditions need to be fulfilled to work with the virtual system.

The controller unit itself provides buttons for controlling the simulation and an important feedback about the real speed of the current simulation compared to the internal clock speed. The behavior is like the real hardware from the Robotic HomeLab kit, but based on the LDL configuration files of the test stands; new modules may be added easily.

V. DISTANCE LAB WIRELESS PROGRAMMING

The counterpart of the presented VMCU platform is the real hardware based platform called Robotic HomeLab kit. Both technologies are accessible through a remote and virtual distance lab platform, named VAPVoS. This system is conceptually fully compatible with the distance lab approach presented in [3] [15] and [16]. However components in these advanced educational platforms are built up on virtual and real hardware which are combined with ICT systems to allow remote access to controller programming feature and visual feedback. In that way both systems can be used simultaneously to overcome single system specific limitations.

DistanceLab platform has a two level architecture. First layer is based on Internet connected servers, located central web host and servers located in every lab. Main web server provides a web based user interface for several labs by allowing compiling the program or calculating the correct values depending on the specific lab device characteristics or interfaces. If user program has passed the validation e.g. microcontroller program is successfully compiled, program will be transferred to a program server located in lab, close to target devices, or send to a virtual hardware device through a software interface. In case of real hardware, the program server connects then with target device and identifies its state. If the device is available and active, the program server resets running program in the selected device, uploads a new program and restarts the device. When uploading is completed, system starts with new program and user can see visual feedback over the Internet connected cameras. In the case of the virtual hardware, the system is restarted on a software base and the visual feedback is directly rendered as an applet in a webpage to the browser instance.

Regarding the real hardware labs, there need to be different approaches for programming the devices. Therefore, a special remote programming solution, as presented in fig. 9 is required. Communication between the real hardware device and the program server is implemented as wireless 2.4 GHz connections. ZigBee wireless protocol is used, first on API mode to detect state of target device and then transfer mode to upload new program. The reason why wireless communication is implemented is to allow controlling not only static systems (wired systems) but also mobile systems. A solution is developed to program wirelessly small mobile robots running for instance in an arena in university lab. The detail overview of mobile robotic remote lab is given in paper [17].

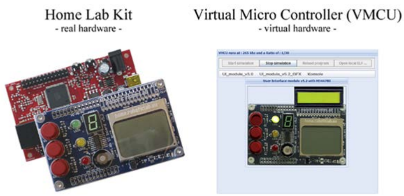

Fig. 8 – Robotic HomeLab kit and VMCU

The benefit of combining the virtual and real remote labs is to give the extended possibility for students and researcher to study or make experiments of microcontroller based systems or experiment machinery over the distance. At first, the solution can be evaluated with the VMCU, where device instances can be multiplied as much as available computing power. After completing virtual tests, which are still in simulated world, user can move to real world platform and continue with same solution in real world environment. The limitations of using DistanceLab platform are in fact that real devices cannot be multiplied just copying them in computer. One device can be controlled only by one user at certain time. By combining presented solutions these limitations can be compensated by both platforms.

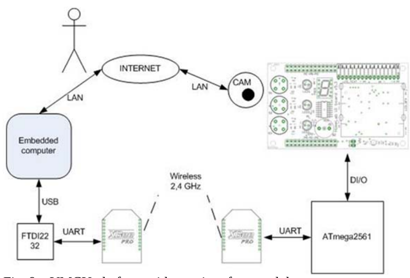

Fig. 9 – VMCU platform with user interface module

VI. DISCUSSION AND FURTHER STEPS

The structure of the VMCU, with respect to LDL as the descriptive language, offers an easy to use microcontroller simulation device that can be extended with additional microcontroller periphery devices. By utilizing the open source microcontroller simulation environment Avrora, different devices from the Atmel ATMega family can be simulated. As Avrora is written in Java, a high level of platform independence and comfortable integration into a web environment is achieved, so that larger audiences can be reached. Nevertheless the calling of information processing methods for each device in each simulation cycle leads to a performance loss. But this disadvantage also has a positive aspect, because as the simulation is working more slowly the underlying process can be better understood, as details of the simulation may not be hidden anymore like in real hardware. By using the LDL configuration files the test stands can be created dynamically and different devices can be combined with the controller. The applets were also designed to work without an Internet connection, so the simulation device can be used without the need of permanently being online.

In the next development step the intention is to add new modules to the controller. It is also planned to create a "physics engine", where real world physics can be simulated, like air pressure, light intensity, among others. Furthermore we intend to enable a math description of for instance temperature curves over time, so virtual sensors can be added. The first prototype for this physics engine is currently tested at Bochum University of Applied Sciences. While the Mixed Reality lab [18, 19] at the University of Bremen merges the real technical world with computerized simulation and visualization in two ways, the VMCU is only a virtualized version of the HomeLab kit, simulating its full behavior, but through LDL enhanced with the functionality of easily adding new virtual embedded system experiments without advanced technical skills.

A. *Conclusion*

In this paper the focus was set on a virtual, web based microcontroller learning environment.

The VMCU was realized to enable an easy implementation of new test stands and microcontroller periphery, like LCD screens, LEDs or even more complex motor and sensor modules.

Through the research, design and development and the following pilots runs in Estonia and Germany, authors asked about feedback about the products. As the pilot is still running and no final feedback is published, the interest expressed is really convincing to work further on innovative learning material for education.

From a group of currently 38 people answering the survey, to the question "Is the VMCU helping you learning micro controller technology", currently 74% agree, while 8% disagree where 18% do not know yet. Asking about "Is the VMCU a good development you would like to tell your colleagues about?" currently 79% fully agree, 11% are not sure and 10% disagree.

Currently there are new modules for the controller, accompanied by a virtual "physics engine" in development. The idea about this physics engine is to simulate real world physics, like air pressure, light intensity, humidity among others. Furthermore it is intended to enable a math description of for instance temperature curves over time, so virtual sensors might be added to the VMCU platform.

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C. Improvements of Multi-disciplinary Engineering Study by Exploiting Design-centric Approach, supported by Remote and Virtual Labs

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Improvements of Multi-disciplinary Engineering Study by Exploiting Design-centric Approach, Supported by Remote and Virtual Labs*

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In the current paper the design-centric approach for mechatronics and smart product design is presented. The novel aspect of the proposed solution is a comprehensive learning concept and environment which includes remote labs, mobile hardware, methodology, learning material and web environments. The whole concept supports fast and student-oriented learning process for acquiring knowledge and practical skills of integrated systems. The concept is applied into practice in the course of several stages. The most recent case study is described in this paper and the course setup proposed. The feedback from students indicates the time spent by the student on the activity, when the course follows the proposed concept. It is apparent that students spend considerably more time than the curriculum requires. At the same time, workload of the supervisor is lower. However, the quality and learning outcomes are higher than those of previous related courses, but without using novel technologies. In the current paper special attention is paid to remote and virtual labs related to the proposed learning concept.

Keywords: distance learning; virtual micro controller; design-centric study; robotics

1. Introduction

With fast advancement of technologies and design methods for developing smart products, demands for future engineers are also rapidly increasing. Future engineers have to be open to innovations and find optimal solutions for problems in very complex engineering environments. In general terms an engineering environment is a complex mix of customer requirements, marketing aspects, engineering tools and creativity. This leads to the need for changes to engineering education in the multi-disciplinary domain. Conventional teaching and studying methods often do not provide necessary knowledge and are not suitable for Internet era learners. To be successful in teaching multi-disciplinary systems, e.g. smart products, it is necessary to bring the learning activities to the Internet, disconnect hands-on learning from fixed places and focus on practical problem based study instead of the standard lecture-exercise method. This can be successfully implemented by taking a real-life problem related to clear industry needs as basis of the study program. Some problems require an innovative approach and creative thinking on students' behalf. To make that kind of engineering study attractive and convenient to students, new tools must be implemented and integrated into the study process. In this paper the design-centric approach of teaching mechatronics and robotics is described and several innovative tools are presented, including modern web technology based online engineering environments. The approach is piloted in Estonia and other countries and is a key component of the Tallinn University of Technology micro controller and mechatronics courses. Fig. 1. represents the simplified tree of the described process and tools involved.

The current paper is divided into the following parts: State-of-the-Art summarizes briefly the existing solutions and indicates deficiencies; the next section introduces the design-centric study process and the open learning path of international mechatronics curriculum on master's level; the following chapter concentrates on the remote laboratory solution which is a key component of novel e-learning in engineering fields; the Blended Learning Concept chapter describes the background and tools used in the proposed study methodology. Finally, the example course setup is described in greater detail and a previous course is analyzed. To conclude, the paper sums up the discussions. In the conclusion the next steps of development are described and approved future projects introduced.

2. State-of-the-art

As project based study and design-centric approaches are both widespread in engineering study at present, no special examples of these pedagogies are included here. However, a design-centric approach requires appropriate tools and learning environment, e.g. special purpose labs, experiments in practical training, etc. It should be

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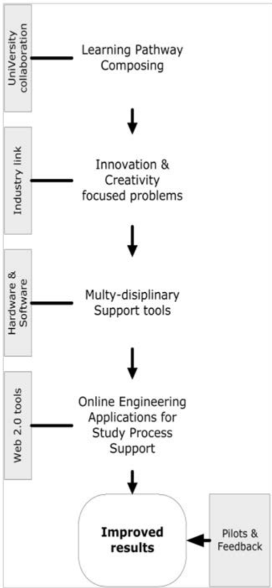

Fig. 1. Simplified learning environment and process tree.

considered that in recent years the Internet has become the main source of information for learners, thus is not possible to ignore it. Although hands-on experiments may seem hard to perform over the Internet or at distance, many new technologies already exist.

Different solutions have been developed and applied to the study process, many of them on an experimental level.

The overview about trends in online engineering and learning experience in remote labs are briefly covered in the guest editor paper [1]. Many initiatives are related to a specific course. For example, one of the most virtualized lab types are found in Electrical Engineering domain. A well known lab has been established in France [2] for conducting remote experiments. DSP based remote experiments are presented in paper [3]. There are several other labs set up by different institutions. Most developers build their own interfaces and have control over their labs.

The general common shortcoming of current remote labs is the course centric approach. It means that the remote lab is designed and developed for supporting a specific course and is not related to other courses and tools. We prefer remote labs as part of more general concept and support practical experience over the Internet in addition to other relevant tools, e.g. mobile hardware—Robotic HomeLab kit. These labs provide valuable practical training in the learning and teaching concept and are not intended to be used independently. Distance engineering study needs not only one option, e.g. remote lab but also real hands-on, conventional supporting material, guidance, etc. Although this paper concentrates mostly on remote labs, other parts of our concept are provided in [4–7].

3. Design-centric approach for smart product studies

At the beginning of teaching engineering studies it is important to consider the personality of the learner, his/her ability to acquire new information and possibilities of arranging study forms. For example, continuous education learners have several limitations of taking part in time consuming lab practices. The proposed approach offers creating a personalized learning utility for establishing a full individual learning program, composed of modules offered by different educational institutions. Obviously, agreements between organizations and active collaboration are expected. In our case international collaboration between universities from Estonia, Germany, Finland, Great Britain and Lithuania has been established and study modules are offered for local as well as foreign students. Students get personal and international learning practice consisting of modules selected by the learner. Fig. 2 describes the master study program where specialty modules (A1–A3) can be selected from different universities considering the learner's personal interest. TUT denotes here the Tallinn University of Technology from Estonia, HBO—Bochum University of Applied Sciences from Germany, KTU—Kaunas University of Technology from Lithuania, etc.

All learning programs comprise consistent modules offered by a certain university, while modules consist of single or continuous courses providing particular knowledge or skills in a relevant field. The course program presented in Fig. 2. has been developed for the smart product course in the Mechatronics curriculum. The study focuses on the design-centric approach where a real-life problem is assigned to student teams and where the successful solution requires creative thinking and integrated activities in a multi-domain space—mostly electrical engineering, mechanical engineering, software design, management and production technologies. These activities have to be performed on time by

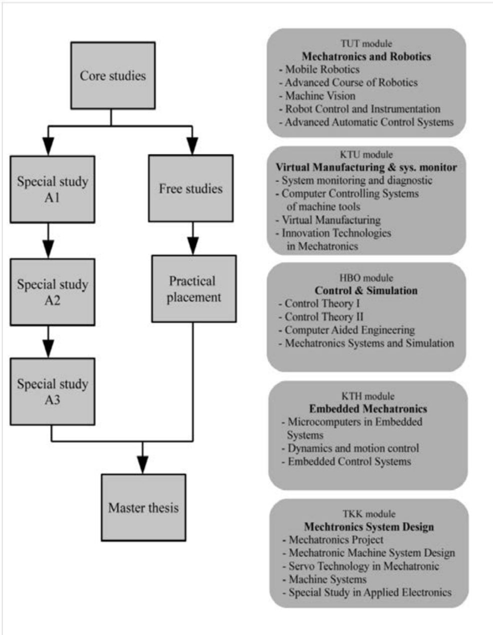

Fig. 2. Learning program and available selective modules for special study.

following budget guidelines and using project management techniques.

The described creation of learning program and personalized study content is not unique; nevertheless it is not easy to work with modules provided by different universities from different countries. The solution takes full advantage of current technology and provides interfaces and access to equipment at distance. It is very important to bring engineering study to the learner's environment, that is today the Internet. However, quality and hands-on experience must not suffer by relocating experiments to the Internet or learners' homes. Standard e-learning systems (like Moodle, Blackboard, etc.) do not provide relevant functionality (practical work) to engineering studies and cannot guarantee fulfillment of this requirement. They are only useful for conventional e-learning activities like presenting static or dynamic material, performing tests and providing communication functionality. However, practical experiments are an essential part of engineering studies, and without the 'learning-by-doing' approach it is impossible to expect good quality learning outcomes. The proposed solution provides several tools and e-systems based on modern web technology to enhance significantly e-learning functionality. The process tree and learning environment links are presented in Fig. 1. Multi-disciplinary support tools consist of hardware sets designed as a modular system for mobile use. Students can use the experiment equipment at home, in their work place or even when abroad. Only a standard computer is needed in addition to the mobile lab set. The same set is already commonly used at school computer classes and libraries. The kit is based on micro controller module and additional modules like sensor, motor, communication and vision modules. The solution is called Robotic HomeLab kit and it is developed in cooperation with universities and private companies from Estonia and Germany. The kit has a specific support environment—Network of Excellence (NoE), providing comprehensive support and resources for Robotic HomeLab users. The important aspect here is that the single functional upgrade does not provide the necessary quality leap, but the combination of conventional and new tools perform the task. The online engineering applications are described in detail in the next chapter.

3.1 Remote and virtual labs

The important part in proposed concept is a set of online engineering tools offering remote lab functionality and providing real and virtualized hardware access.

The remote lab system providing access to hardware is denoted as DistanceLab. The platform enables to control or monitor real equipment placed in the university lab. The DistanceLab can use LabView or any other custom built interface to access different hardware. In our example the mobile robot interface is developed and implemented providing wireless access to small mobile robot running on the university lab. Students can book one device and start practicing to control the system by programming its core controller. The results of the work can be monitored over real-time video feedback. Several tasks can be assigned to teams to develop system behavior on different complexity levels.

The system exploits a three layer physical system where the user interface is served by the standard web server and the user can access it with his/her everyday browser. The web interface is developed by using common LAMP (Linux, Apache, MySQL and PHP) server platform and the system architecture following the Model-View-Controller concept. The second layer is a program server which runs currently on embedded Linux operating system and communicates directly with lab devices. Where the communication between web server and program server uses standard Internet link i.e. TCP/IP, the communication between program server and devices are performed wireless. The reason for using the wireless link is that the devices in the remote lab are mobile robots. They can move around in an arena and it is impossible to run the mobile device with a wired link. For tasks, like 'resetting' and 'remote programming' the device a wireless communication is initiated and the device stops current program and uploads a new one. The wireless link exploits a ZigBee protocol enabling great distance and cost effective wireless solutions. The feedback of the device action is streamed over IP cameras providing real-time feedback to the student.

The other part of the remote lab system is a virtualized micro controller unit and peripheral modules VirtualLab (VMCU). The VirtualLab has virtual versions of the hardware modules from real experiment hardware from Robotic HomeLab kit. The modules are visualized and users can generate as many instances of the specific module as needed. Thus, several users can work at the same time with the same (software) unit. When using the real equipment only one user at a time can control it. According to the concept, solutions have to be tested and practiced on the virtualized module. Next, teams that have passed a pre-defined level can move to the real hardware. All described activities can be performed over the Internet utilizing a standard web browser. Thus, practical exercises can be performed remotely but still using the real or virtualized equipment according to the need or course arrangements.

The main component of the VirtualLab is a micro controller simulation engine built up on the Avrora framework [8]. On the VirtualLab a visual interface was developed and different peripheral devices (modules) are provided. Peripheral devices enable studying different smart system functionalities, e.g. digital input-outputs, analog-digital converter, pulse with modulation, etc. The functionality study is related to real world components. Students link the functionality with a real device. For example, digital inputs are studied by use of buttons, outputs by use of LEDs. The analog-digital conversion is studied through temperature sensor producing an analog output reflecting the measured temperature. All peripheral modules in VirtualLab are described by XML where all single components on the modules simulate precisely the real component according to the manufacturer's datasheet. Fig. 3. illustrates the integration of DistanceLab, VirtualLab and HomeLab kit.

As stated in previous sections, engineering study needs practical hands-on experiments and also system control in order to provide necessary knowledge and skills. It is not easy to provide the same hands-on experience over distance. Here the described online tools help to solve the dilemma between distance learning and hands-on experiments. Use of the described tools in the study process follows the student's personal study achievements and the logical course or curriculum structure. For example, in mechatronics one study module can use tools in the following order and purpose.

In first stage, the single functionality, e.g. micro controller interrupts are studied, practical exercises are performed on the VirtualLab User Interface module. When the virtual solution functions, one can continue with the real hardware, i.e. Robotic HomeLab kit and experiment the same solution on it. This can be done at home, if the hardware is available for home use, at school or library (this depends on the university policy in most cases). After the single functionalities are studied and exercises performed the student can book an experiment device, i.e. mobile robot on the DistanceLab.

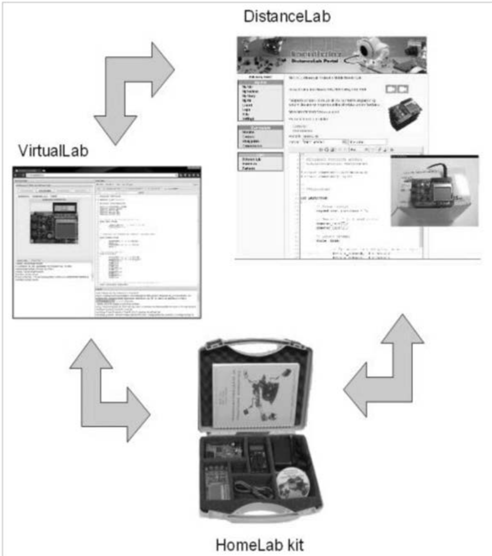

Fig. 3. Set of practical tools.

The experiment device is usually a small system which exploits all single functionality as a functional system. It enables testing his/her acquired knowledge and skills on the system which is usually much more complex than a single function. However, practical experiments with online and mobile tools are part of the study and need local manuals, as well as several other supporting tools and environments. The next sections give a brief overview of the concept supporting online tools and study process in general.

3.2 The blended learning concept

The Blended Teaching & Learning Concept (BTLC) [6] does not cover only the university education but starts at primary school and evolves into lifelong learning. The concept frames teaching and learning environments, tools and methodologies. All education levels use the same platform and tools but on different complexity level and under different guidance. The concept has been applied into practice step-by-step on all educational levels in Estonia since 2007. The results are promising and interest among young people has increased considering the intake competition rate on mechatronics curricula at the Tallinn University of Technology.

As mechatronics and robotics are very practical domains, the constant hands-on experience has to support theoretical studies on every level. It is especially important to introduce robotics to newcomers and young people in an attractive way and assure them of their ability to do engineering and easily program a robot. According to our experience, the Lego Mindstorm NXT robotic set is a good tool to start with. Thus, robotics can even be taught in kindergartens, although the first acquaintance with robotics is usually done in primary school. That ensures fast results important for keeping the motivation up for robotic studies. Several standard Lego NXT robotic solutions are built, used in school competitions held during autumn and spring holidays. On secondary school level the robotic platform is changed to the Robotic HomeLab kit, developed by our consortium. It is important to offer the next step as Lego may bore students after they have played with it for a while. Therefore, the concept offers the next logical step where teachers introduce a convenient micro controller based platform. In Fig. 4 the kits used in our concept are set on the axes. When moving from a simple platform to a more complex one, graphical programming is replaced by C/C++ source code programming although the algorithm remains as a model of the system. In that way students learn that

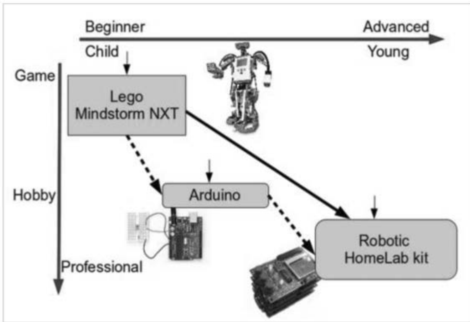

Fig. 4. Robotic educational platforms.

the system behavior can be independent from the target physical system. However, the main concept of robotics: sensor-control-actuator is already familiar and therefore easy to be moved to a new platform. The content of practical projects is also integrated into real life systems (e.g. intelligent control of the smart house). This two-step approach enables a fast start, without losing the motivation and students can reach a high level at the end of secondary school with a minimal study load. If the change feels too rapid for some students, an optional middle course is offered with the Arduino platform. The Arduino micro controller [9] prototype boards have had lots of attention during recent years and can be considered a means to launch from toys to the professional world.

The mechatronics course is very often organized around a design-centric focus. In many cases the course consists of a practical application designed and manufactured by the students. The application is usually a moving robot and at the end of the course a competition is held. Several popular robotic contests are held in Europe, including sumo robot contests, Eurobot [10], etc.

The following case study describes the design-centric mechatronics course where innovative tools were used and remote hands-on experiments applied.

3.3 Course setup

The case study course was added to the mechatronics curriculum during last semester in bachelor study studies and students had to work intensively for two months before presenting their thesis. Although the course was meant for the bachelor degree students, the same structure and concept is

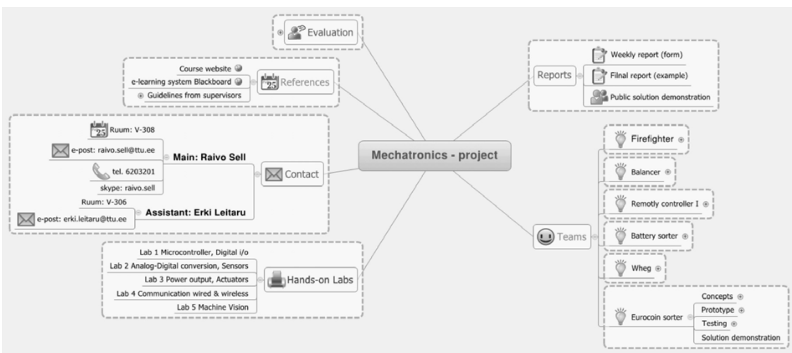

Fig. 5. Mindmap of the course.

currently used at higher vocational schools (but on another level of complexity). The main purpose of the course is to put knowledge acquired during previous studies into practice by designing and building an integrated mechatronic system—smart product within limited time and with modest budget. The work is performed in groups following the basic project management process. The course is described by supervisors by one graph using Mind-map technique. In Fig. 5 the course setup in spring 2011 is shown.

The course setup is based on Blended Teaching & Learning Concept, described in previous chapter and works [6, 7] and utilizes most of the aspects and resources the concept offers. The introduction and most on-site practical experiments were performed by Robotic HomeLab kits [11] either in a classroom or at student's home. The mobile lab kit allows carrying all necessary hardware easily, and often the experiment was started at school and continued at home. Thus, there are no time limitations and the team could finish solving a study problem at home. At the same time, the VirtualLab environment was available for all students and those who lacked access to real hardware could meanwhile test the source code on the virtual micro controller and experiment boards. The solution is designed to be identical between real hardware and virtual hardware modules. This solution boosted the development process and there are no time or location limitations for performing practical programming or experiments. As the main goal of the course is to design a real product based on their acquired knowledge, all teams were provided with different product ideas. In all cases, these ideas smart products where the results to achieve were the combination of smart mechanics, reliable electronics and control logics. The main components of the smart product were taken from the Homeab kit box. At the same time the real mechatronics system built upon the same components was available via the DistanceLab. Small size mobile robots were accessible over the Internet to test one's knowledge and perform experiments by using the system. As real hardware is always limited, every group can book and control only one device without being interrupted. The feedback is provided as described before via the DistanceLab cameras. As soon as the robot's battery runs out it goes automatically to charging station and is back in operation after charging.

Most of the work was performed with the support of hands-on tools like DistanceLab and VirtualLab but without direct guidance of the supervisor. Presentations were held every two weeks to ensure smooth working and to fix practical problems. In addition to practical tool support the special web environment—Network of Excellence was used to provide all necessary data and a reporting environment. An important aspect of the course was the final public demo of the developed system. The public demonstration forces the students to finish all activities in time and work on marketing and presentation aspects. Experience has shown that students are happy and proud to present their work in public even if they had initial doubts.

4. Discussion

The current versions of BTLC and the online tools are operational in Estonia and Germany and are being implemented in Finland, Lithuania and latest in Turkey. Currently, active development is run by integrating new interfaces for the DistanceLab system to control more different experiment devices found at universities. Recent projects have been approved and are launched in October 2011 focusing on the establishment of a network of DistanceLabs and VirtualLabs where universities can share resources and cooperate actively in the engineering field without border limits and having free access to labs. A second approved project focuses on the Virtual Academy concept where a common platform for distance education, utilizing HomeLab kit and DistanceLab, as well as Network of Excellence will be developed. This platform can be seen as an integration platform. In addition, this project provides a component for European Credit Points for Vocational Education (ECVET), featuring a detailed description of learning tasks.

At the beginning of 2012 new feature Learning learning situations will be developed and integrated into BTLC. Learning situations are introducing an engineering problem, providing background information and setting up a task for a student or student group which can be solved by using online engineering tools described in this paper.

Several issues have to be considered when using or setting up online access to hardware. Some key points considered in our online tools and implemented in software systems are raised briefly here, but the scope of this paper precludes detailed discussion. First of all, security has to be considered, the system has to be secured from misuse and system faults, especially if heavy hardware and moving devices are involved. In case of mobile devices there is difficult to provide constant electrical connection for power source and programming and it may necessary to develop an automatic charging system and power monitoring. The availability for the VirtualLab is easier to achieve as it depends on the server computing power. The flexibility of the system is an important factor as technology develops rapidly and new labs may need to be integrated into the system.

5. Conclusion

Practical hands-on experiments are absolutely essential in engineering studies and cannot be avoided. On the other hand, distance e-learning is increasing in all fields of studies. At present the Internet is central to social and educational life of most students. If they cannot find information about engineering studies, they may assume it does not suit for them at all. In the current paper we described the concept and online tools developed to solve this dilemma and we were successful in putting theory into practice, from primary school level to continuous education courses. Online engineering tools are used daily in several universities and schools in Europe. It is time to take the next step of networking remote labs and initiating further international collaboration.

During recent years this concept and the online engineering tools have been applied in various courses. This paper has analyzed one of the courses and its benefits. The main result of the described case study was the drastically increased time spent voluntarily by students on the course. The second main aspect was the acquired knowledge and practical experience of problem solving and developing a smart product without much additional help by the supervisor. Students appreciate the novel concept of the course study process and feedback has indicated they prefer it to the conventional course. We believe that our approach has successfully combined distance learning and engineering practical work requirements, while study quality has improved. However, there are several possibilities and interesting challenges to work with and develop an all over Europe network of remote labs.

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D. Lab Description Language - A framework approach for describing and mediating remote and virtual labs

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Lab Description Language - A framework approach for describing and mediating remote and virtual labs

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***Abstract*- More and more universities and schools across the world are developing different types of remote labs for their own operations. However, there is very little evidence at the present time that such local labs are used by or shared with other institutions in order to provide educational support for a wider range of students on a regular basis. Several other virtual and remote laboratories have been developed for a variety of disciplines. But these diverse proprietary interfaces, software components and implementations for each experiment are a problem for learners and teachers (no common user interfaces and APIs are used). Therefore, it is hard to integrate new remote labs or create virtual labs for non-engineers. Due to incompatible software implementations it is also a challenging task to integrate external labs into an existing lab platform. That complicates the sharing of labs between different organisations and universities. With the approach of "Lab Description Language" (LDL) authors of this paper are introducing a new framework concept for describing and mediating remote and virtual labs. This concept is demonstrated using the example of the Virtual Micro Controller Unit (VMCU) developed by paper authors.**

I. INTRODUCTION

In order to solve the problem of providing practical skills to students due to the lack of equipment and funds in educational institutions, technology enhanced learning based on the sharing of equipment between institutions is suggested for wide-scale implementation across European countries [1,2]. Advances in Internet-based technologies allow institutions, SMEs and private individuals to access equipment of other organisations. However, the main problem today is that there are no standards or recommendations regarding the requirements for such equipment (electrical signals, communicational protocols and compatibility of software). There are merely some suggestions presented in [3,4,2], but no DIN, ISO, or IEEE standard. Changing the view to subparts and subsystems, there are existing different (semantic) descriptions for various science areas, like sensor descriptions. For instance Compton et al. analysed 12 different sensor ontologies in 2009, presented in [5]. While some of them (like Avancha [6] and CESN [7]) are merely about description of sensors, other like OntoSensor [8] are also capable of descriping 'components', or like OOSTethys 'processes' in addition. Their conclusion draws the statment, that a "combination of OntoSensor and the CSIRO ontology represents the current limit of expressive capability for semantic sensors", but none of them is able to deal with the whole context of sensor descriptions [5].

For user interfaces it is almost same situation. Various descriptive approaches are existing and discussed in the Model-Based User Interfaces Incubator Group at W3C. These approaches can be separated into industrial (Collage, Flex, Open Laszlo and XAML for instance) and research driven (CAMELEON Reference Framework, MARIA and UsiXML for instance) ones (compare to [9]).

Another point about the description of equipment being used for industrial purposes is that this equipment is not necessarily convenient to be used in the educational process. Moreover, the ergonomics of industrial equipment are often very different from the ergonomics required for the equipment to be used in educational organisations ([10]). This means that it is not a straightforward process to implement remote controlled equipment in the educational environment.

Universities across the world are developing different types of remote labs for their own interests, as presented in [1], [11] and [12]. However, there is very little evidence at the present time that such local labs are used by other institutions in order to provide educational support for a wider range of students on a regular basis. The common web browser is widely used to access remote and virtual laboratories [13,14]. Authors in [15] have introduced the concept of "experiment as a service" and developed a service-based software infrastructure for remote laboratories, called DCL (Distributed Control Lab). Examples of integrated experiments available on DCL are "Higher Striker" (a real-time control experiment), a programmable logic controller, and embedded real-time control applications. This work has been undertaken under the Vet-Trend project [16] with the main objective to build an open infrastructure for conducting robotics and real-time control experiments from the Web. Unfortunately, this concept has not become widespread so far since there is no established standard and the software components used in DCL are not publicly available.Authors in [17], under a project called VISIR (Virtual Systems in Reality), developed software to allow users in various universities and other organisations to set up online lab workbenches for electrical experiments. The software is used by two universities and students can perform simultaneous experiments on online workbenches. Several other virtual and remote laboratories have been developed for a variety of disciplines [18, 19, 20] However, the diverse proprietary interfaces, software components and implementations for each experiment are a problem for learners and teachers (no common user interfaces and APIs are used). Therefore, it is hard to integrate new remote labs or create virtual labs. Due to incompatible software implementations it is a hard task to integrate external labs into an existing lab platform. That complicates the sharing of labs between different organisations and universities.

Another major problem that slows down the evolution and distribution of distance labs is that very few qualified staff members are capable of providing lab equipment on the Internet, not to mention that it is even more complicated to completely virtualise given hardware components. A strong indicator for this is that most of the labs distributed are engineering related; teachers from other disciplines who lack an affinity to programming are less likely to provide their labs on the internet since they lack the technical knowledge and support to do so. To deal with this issue, the goals of iLabs project at Massachusetts Institute of Technology in USA, were to develop a suite of software tools that facilitates online complex laboratory experiments, i.e., "minimize development and management effort for users and providers of remote labs, provide a common set of services and development tools, scale to large numbers of users worldwide, allow multiple universities with diverse network infrastructures to share access". Authors in [21] have compared three web services based architectures of remote laboratories, DIBE ISILab (Internet Shared Instrumentation Laboratory), HPI DCL (Distributed Control Laboratory) and MIT iLab, according to user interactions and interoperability between remote labs. All of these architectures collect in a web service interface all the functionalities exposed by the lab, and use work sessions to structure measurements and store data sent or received from the instruments. They stated also that "structuring remote laboratory functions as a set of services has the major advantage of allowing the sharing of the physical experimental setup, while leaving the possibility of customising the client application interface". From the interoperability perspective, the authors have tested and proved the possibility of sharing remote experiments between different institutions, like thesis authors did in the frame of their own lab development. Most of the existing Labs are tailored lab-specific experiments and use diverse proprietary interfaces and implementations, but there is no common user interface and no common APIs, nor a common description about them. Despite that, many labs share similar requirements; new experiments require new developments, logic, connectors and user interfaces. In other words, technologies used in current labs mainly lack reusability and interoperability, for instance they are not generic enough to be reused in designing and integrating new Labs. Also, most lecturers do not have wider experience in interfacing with existing labs, mainly developing client user interfaces.

The application of distance and remote labs is becoming a major topic among the scientific community. In the latest call the European Union provided funding's for several large scale projects within the frame of distance and remote lab application and implantation.

As shown in this chapter, virtual and distance labs are already in use by various educational institutions. There is a lot of work to do in this area, yet. Scientific sound evaluation of learning outcomes as well as long term studies are required to prove the effectiveness of these approaches. The proper integration of distance labs into the daily teachings would also require distinct cooperation's between educational institutions since sharing of expensive lab equipment is a key criteria for the added value of the distance lab concept.

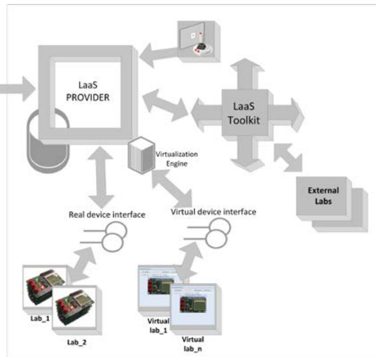

Fig 1. Technical vision using LDL for mediating hard- and software

II. CONCEPT OF LDL

Currently, as stated in the section before, there is very little evidence for significant sharing of distance lab hardware between different institutions. The lack of common standards in lab definition and connectivity specifications is a major impediment to the adoption and wide-scale networking of labs for teaching and training purposes.

Educational facilities have their own technological approaches, so sharing is very complicated since external software components and data sources cannot be integrated into existing platforms without major expense. The requirements in technical knowhow, programming skills and time are too high for most teaching staff.

Furthermore, there are no common documentation sets, software platforms or reusable libraries to reduce the workload for a remote and virtual lab provider. The complexity of the common approaches delays the evolution of distance lab approaches and hinders a thematically wider range of potential lab providers and users from participating in distance lab networks. As a result of this problem, there is an urgent need for unification in this field. Therefore, authors goal is to solve this situation by providing an early draft for descriptive lab integration (LDL). Figure 1 is introducing the overall concept, including LaaS provider and LaaS Toolkit Based on the section before it seems nonsensical to provide a roughly new description language, without taking existing approaches into

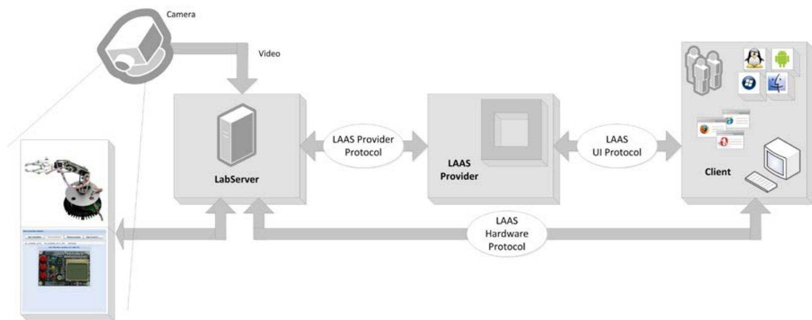

Fig2. - LDL and protocols

account. Therefore LDL is integrating existing best-known solutions and is enabled to be extended by linking to other concepts.

A. Technical concept

Lab Description Language (LDL) allows transparent access to laboratories independent of the type of the system, because LDL allows labs/experiments to be defined in an abstract manner, as presented in fig.2. As a long-term goal LDL will be proposed to the international community (in frame of a possibly funded IP project) as a potential prototype universal standard for specification and connection of remote and virtual labs and associated components. The consideration for adoption of such a draft idea by engineers, technologists and scientists will aid the longer-term success of the networked labs and encourage participations.

LDL provides the ontological basis to develop a web-based platform incorporating a comprehensive toolbox of components, component-interfaces and access interfaces. The standardisation of required interfaces and the development and free distribution of software components for lab integration and distribution solves the major problems described in state of the art. LDL will allow transparent access to laboratories independent of the type of the system. LDL allows labs/experiments to be defined in an abstract manner, all objects needed to integrate existing Labs (button, editor, widget, interface to software tools, e.g., Matlab), which can represent different laboratory components, will be implemented via LDL in terms of tags and attributes based on OWL2 [22].

B. Lab Ontology

LDL provides the ontological basis to develop a web-based platform incorporating a comprehensive toolbox of components, component-interfaces and access interfaces. The standardisation of required interfaces and the development and free distribution of software components for lab integration and distribution solves the major problems of Internet accessible labs. LDL will allow transparent access to laboratories independent of the type of the system. LDL allows labs/experiments to be defined in an abstract manner, all objects needed to integrate existing Labs (button, editor, widget, interface to software tools, e.g., Matlab), which can represent different laboratory components, will be written in LDL in terms of tags and attributes based on OWL2.

For instance a description of the green LED looks like the example given in fig 3 and fig 4.

LDL in its current state can be utilized to describe the interconnection of micro controller based devices, their interfacing to remote lab platforms, such as DistanceLab. In addition LDL offers a comprehensive way to describe and mediate the interfaces of external labs to be included into a DistanceLab environment, as presented in the source code in fig 4.

The lack of a common standard is also responsible for poor participation in distance lab projects. The requirements in technical knowhow, programming skills and time are too high for most teachers and university staff. Furthermore, there are no common documentations, software platforms or reusable library's to reduce the workload for a distance lab provider. That is the main reason for low participation rates and also the reason most lab providers are from software engineering related fields. The complexity of the common approaches delays the evolution of distance lab approaches and hinders a thematically wider range of potential lab providers and users from participating in distance lab networks.

That's the reason why author proposes the standardisation of all distance/virtual lab communication interfaces:

1. Standardised description language for lab equipment
2. Standardised communication between lab hardware and the lab PC
3. Standardised communication between the lab PC and the server (plug-and-play of labs)
4. A unified method to easily integrate Labs into every web platform (laboratory as a service concept)

These web platforms can be any learning management system like Moodle or Blackboard, or it could be the homepage of a university of even of a private web site. Integration of labs will be possible on every web platform that reaches certain technological requirements. As an example: one should be able to integrate a distance lab on a website as easily as integrating a YouTube video there (and this is very easy).

All objects needed to integrate existing Labs (hardware connectors, bus systems, streams, buttons, editor, widget, interface to software tools, e.g., Matlab), which can represent different laboratory components, can be defined in LDL in terms of tags and attributes in form of an ontology formulated in OWL2. General idea was to develop an integrated description which covers all aspects of distance lab integration. The approach unifies processes among all parties working with distance labs, the provider, the teacher and the learner. Finally in last stage the four interface descriptions create a plug and play distance lab network which is open in all directions. Teaching staff is able to integrate all available distance labs into every web site or LMS.

Interface standards that are created are the following: a) real and virtual lab communication, b) UI description interface, c) a provider protocol, dealing with:

- real and virtual lab communication, about hardware and virtual components (cameras, sensors etc.), interfaces and interaction with the labs
- An abstract GUI description interface - Every lab needs at least one user interface; most likely there will be more than one feasible user interface for each lab. Depending on the experimentation done in a specific lab, different instruments are required. For example, a simple embedded programming lab, dependent on the task the learner is given may require various hardware to accomplish his task, like an oscilloscope, on chip debugging or many other kinds of measurement. This is a huge challenge for the user interface description. A sound method has to be found to connect the real/virtual hardware to the compatible GUI components. The second important topic on this interface is to find a standard that regulates the integration of LaaS labs in third party web platforms (like Blackboard, Moodle or proprietary solutions built by a single university).
- Lab provider protocol, for registering the labs on a provider system, allowing and controlling access to the labs. The master server is an instance which controls and enables communication between the single components of the system, like learning platforms and lab providers.

In the scope of this research the general outline for LDL was set. Ideas and suggestions for a possible widespread implementation can be found in the next section.

III. Further Development and Future Outlook

Currently, a holistic soft- and hardware toolbox including documentation for automated plug and play distribution of remote labs is built upon the general LDL idea, mediating the ontology formulation to real interaction and labs beyond the draft implementation in this thesis.

This envisaged toolbox will be easy to operate so that a provider of distance labs will no longer need programming or advanced technical skills. Hardware integrations as well as provision of ergonomic user interfaces should be handled by this toolbox. All lab related devices (labs themselves, intelligent tools, UI, LMS) can use LDL to communicate, as LDL is about the description and the protocol implementation of the overall system communication. This is delivered by a web service approach named Laboratory as a Service that is realised by components/software being developed to use LDL for communication, the universal approach for lab description and integration.

LDL has the potential to streamline the creation of new labs and make many more labs available to the educational community engaged in the project. The meta-language is designed and built using existing standards for the semantic web to encompass all known requirements, but ensuring it can evolve over time with technological developments.

To implement the early LDL draft into productive real lab environment, the following tasks have to be undertaken:

1. Technical analysis of common components, detailed analysis of hardware communication protocols and standards, formulation of a set of requirements for generalisation of analysed elements.

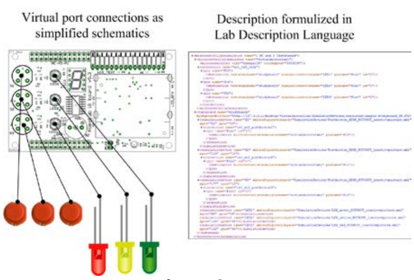

Fig 3. - Description of virtual port connection in LDL

```
<simulationdevice type="LDE"
                 classfile="virtualmicroclab.simdev.led.LED">
<parameters>
  <parameter name="color" type="String" value="green" />
  <parameter name="connection information" type="String"
             value="add your device description here." />
</parameters>
<resources>
  <resource name="activePicture" type="image"
            path="components/electrical/LED/Green" />
  <resource name="inactivePicture" type="image"
            path=" components/electrical/LED/Transparent />
</resources>
<inputpins>
  <pin name="Pin0" id="0" />
</inputpins>
</simulationdevice>
```

Fig 4. – Simulation Device Description in LDL

2. Analysis of existing labs as well as labs provided by external providers. Identification of common components, common approaches in integration and estimation requirements to a standard given by those identified elements.
3. Resolving the hardware into generic components like: sensors, actors, video streaming devices, audio streaming devices. Components identified need to be exhaustive to cover the entire lab hardware with generic components. Also, strategies have to be developed for components that can't be covered.
4. Parameter and Hardware description of generic components, by formulating hardware descriptions into LDL ontology and distinguishing reasonable parameter sets to ensure the hardware components can be configured for every possible scenario.
5. A Real-time communication protocol requirement analysis needs to be implemented, following the requirement definition for a communication protocol that can be used to control the hardware in a distance lab that is beyond the state of the draft LDL.
6. Generalisation of standard GUI components (Source code editor, Video Stream viewer, Input devices (buttons, regulators, switches)
7. Also, metadata for a booking system must be implemented.
8. Furthermore, the access to distance labs via mobile devices such as smartphones and tablets can be supported as well since the LDL approach is device independent as well as independent from any operating system or specific server infrastructure.

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E. Integrated Concept for Embedded System Study

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Integrated Concept for Embedded System Study

Abstract

Embedded systems are in everyday life and there is a frantic need of well-educated developers, designers and programmers in this field. The domain itself is in a big change because the borders of pure ICT and embedded system are fusing and according to this process the skilled workforce is even more needed. It is important that ICT education will become more and more to real systems education, instead of just computer software programming, and in most curricula these two domains are still separated. The paper addresses to the novel solution for teaching and learning of embedded systems and robotics based on internet technology. The proposed concept builds the bridge for simple and logical study process by using ICT for controlling and understanding real word processes and situations. The solution is covered with hands-on mobile hardware kits, collaborative e-tools and remote control of lab devices. On the second part a case study is presented and some aspects of results are pointed out.

Keywords: embedded systems, study concept, micro controller, education, robotics

Introduction

The education of Embedded Systems, belonging to the fields of Computer Science and Mechatronic has got a lot of attention in the last years and the overall importance is still heavily evolving. This is a logical process, as these subjects are more and more entering into daily life. Smart products are spread into buildings and homes. These devices are Mechatronic and embedded ones in their nature, because the software part increases quite fast in addition to mechanical and electronic parts. In fact the programming of smart products takes an advancing role in the development of future applications. This leads to the issue of good education in the mentioned fields, especially in programming of embedded devices, to ensure continuous evolvement and high quality products in the future. It is an important challenge for educational institutions to keep up with the fast development in innovation process. Biggest issues seem to be the lack of knowledge and qualification and also motivation with teaching staff, as well as disposability of mostly expensive ICT based learning material. In addition the lack of place in classes for capacious equipment plays a role. The best way to counter the high future demand of professionals in the mentioned fields is to spark young people using and exploring these technologies. Modern ICT based content can ensure the success of this idea. Another point we were dealing with was to exploit modern Internet technology for education in the mentioned fields to make them more attractive for young engineers. Within the following sections the different parts of the overall concept are introduced, which have been developed in the frame of joint EU projects ([1], [2] and [3]) since 2007, followed by detailed descriptions of each subpart.

Embedded Systems

In contrast to a normal operating personal computer (PC) an embedded system is indented to work for a few specific functions included into a more complex device which often includes mechanical and electronic parts. Today a embedded device can control many devices in common [4]. The processing units in an embedded device vary from quite a lot of different architectures, where two categories are available (micro controllers and micro processors). The range of CPU architectures encompasses as well Von Neumann, Harvard architecture as well as Reduced Instruction Set Computing (RISC) and non-RISC CPUs.
In Mechatronics and Computer Sciences mostly the AVR (also AVR32) and ARM architectures are used for the daily education in the embedded systems field. In the presented Integrated Concept for

Embedded System Study we are utilizing the AVR & ARM technology for the HomeLab kits assisted also by additional hardware.

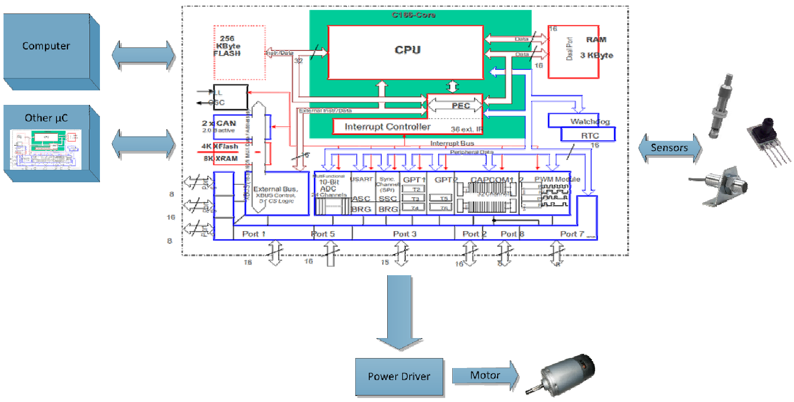

Fig. 1. Example of embedded system core

Integrated Study Concept

Integrated study concept comprises all aspects of teaching and learning the robotics. For that reason our approach is also denoted as Robotic Teaching and Learning Concept. The core components in the concept are the hardware and methodology. The most recognized hardware in the robotic study is the micro controller based development kit. Here we have developed a new solution based on AVR and ARM cores. There are also several other hardware kits used in the robotic study. Most well know is definitely Lego Mindstorm NXT [5], but also some less known like Mechatronic Learning Concept [6], Arduino development shields [7] or micro controller manufactures development kits [8, 9]. The main difference between the existing hardware and methodology is that our concept covers full range of aspects from robotic education. This includes hardware, software, and study material, teaching methodology, e-environment and distance learning facilities. In addition the international collaboration, joint projects and events are integrated into the concept implementation.
Another difference is the strong focus on teaching aspects which are quite important according to our experience. One reason is that high level domains like robotic, needs innovative teaching approaches and methods where conventional lecture-practice methods are not applicable anymore and do not reach the young people. It is easy to lose first interests if the teaching methods are not modified according to young people needs, where the most important communication channel is Internet. About exploiting the possibilities of Web 2.0 the robotic study is much more effective and the initial attractiveness of the field is not violated.
The mentioned Robotic Teaching and Learning Concept hardware part is built on a standard micro controller system based on an ATMega2561 controller unit. The hardware set is designed for multi-purpose, meaning that it is easy to use for studying the simple function or also use the components as a control unit for the complex mechatronic system. The novel study aids, in form of a large set of material, exercises and tutorials to directly use the new hardware makes it different from known implementations, where at first stage a longer investment of time is needed for teaching the basics.

One of the most important aspect of today's world - international collaboration and multilingual cooperation is included into the concept. It is especially important in Europe as so many different languages and cultures are living together and where closer collaboration is a key factor in the future to compete with Asian and American competitors. The concept described in Fig. 2 below points out the teacher's and student tools supporting the learning process. However the tools are obviously overlapping, for example traditional textbooks and modern hardware kits are used by both parties. Although the web support environment is also intended for teachers and students, there is a special section only available for teachers. It is possible to create closed groups in the project environment, if the material is not intended for the public view. Nevertheless most of information and source is available for public and does not even require any registration.

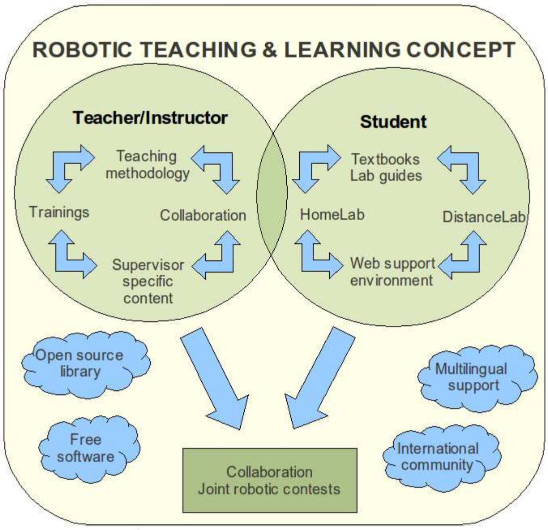

Fig. 2. Integrated Study Concept - Robotic Teaching & Learning Concept

The Robotic Teaching and Learning Concept incorporate several components as presented above. The following chapter is describing some of them which are most tangible and recognized. Several other components, like free software, teacher training etc. cannot be included into the paper due the limitation of a single paper. Most of the components in the concept are in active development and new content or features is presented in the web every week. For example the next foreseen languages are Lithuanian and Russian and in near future also Turkish. The rapid development is also taking place in hardware part where virtual micro controller unit (VMCU) is going to be released during this year.

The most tangible components of the concept are:

- Methodology description
- Course outlines for the different educational levels
- Robotic HomeLab Kit [10]
- Open Source library for HomeLab
- Development and programming software
- Robotic DistanceLab
- Virtual micro controller unit (VMCU)
- Network of Excellence - Robotic HomeLab Community [11]
- Project space
- Textbooks
  Traditional textbook are composed and published as this form of learning is still needed. However the content of the book is also issued as a e-book to keep the content up to date. Paper books issued so far:
    - "Integrated Systems & Design" [12] in English
    - Hands-On lab exercises book [13] in English
    - Micro controllers and Practical Robotics [14] in Estonian
    - Micro controllers and Practical Robotics (in progress) in German

The Hands-on Hardware - Robotic HomeLab Kit

The Robotic HomeLab kit (Fig. 3) was initially developed in the frame of life-long learning project managed by both authors. Several European universities and companies have contributed on the testing and piloting process. The development has been continued after the end of the project and to date the second generation is reached.

The Robotic HomeLab kit is a mobile, ready to use small test stand packed into a handy case, which can be connected to PC and operated in computer class, home or working place. The aim of the kit is to provide a practical and effective hands-on training. Student can combine various solutions on different levels of complexity and functionality, based on the modules inside the kit. The main feature of HomeLab kit is the mobility – it is a small and compact and all modules with necessary tools are seated into the box. Taken the current development status into account, the HomeLab kit offers for example hardware and exercises for 7-segment LED display, graphical LCD, sensors (temperature, light, infrared, ultrasonic, etc.), different motors (DC, servo, stepper), as well as a networking module (for Bluetooth, Ethernet and ZigBee). The advanced HomeLab kit based on ARM controller offers in addition CAN and USB networking functionality targeted to the automotive and advanced robotic sector.

Simple and easy to install software is used to connect main controller to computer. The software is a combination of commercial, but free software, open source software and our own software offering the complete free development tool set for Windows, Linux and Mac OS X platforms. This is particularly important because the student can start practical experiments in school and then continue the work in home or even in his/her workplace without bothering himself with licences and software fees. Experiences from authors' several European projects, where pilot tests were performed in different country illustrate the quicker start-up while working with the HomeLab kit than with other conventional solutions on the market.

Together with DistanceLab application and web environment the HomeLab forms integrated learning concept helping to make engineering studies more effective with practical hands-on experience [15].

Fig. 3. The Robotic HomeLab kit

An important part of HomeLab kit is a specific developed software library which is open source for all users. The library enables to access peripheral devices much easier and user does not have to bother himself with complicated register programming which is a part of usual micro controller programming. One may argue that programming the registers is absolutely essential for understanding the nature of the micro controller, but the real life situation limits quite often the time and other resources which can be consumed for the studies and by using the software library the student can pay more attention to the system behaviour logic instead of trying to have precise control over the controller by manipulating the registers. However the basic knowledge about the registers is definitely needed and therefore the first lab is usually done without using the library.

Remote Access to Hardware - DistanceLab Environment

The Robotic DistanceLab solution for the education and professional use consists of a web interface and a accompanying set of hardware, providing the access for micro controller based systems. The online systems are divided into labs which can be either virtual or real ones. Real labs are denoted as DistanceLab where every lab consists of several devices. One of the first lab was established in Tallinn 2008 where HomeLab kit was laid on the arena. The device components are taken directly from the kit, meaning that students who have no real hardware kit, can still use it, but over the Internet. The second implemented lab comprises numbers of mobile robots made from components from HomeLab kit and which can be programmed over the Internet. The mobile robot specific interface enables to compile and execute the controller software written in C or C++ language and transfer it to the real robot acting on the arena in university. When new program is compiled and sent out by program server, robot interrupts its current routine and acquires new algorithm. User can monitor the real actions over two real-time cameras. The programming interfaces, together with the images of robot in different configurations are shown on Fig. 4. The didactic link between both the DistanceLab and the HomeLab kit is, that most devices in the DistanceLab are using HomeLab Kit hardware components. Therefore it is possible to train at home a single functions and then access to more complex system over to Internet and continue the training.

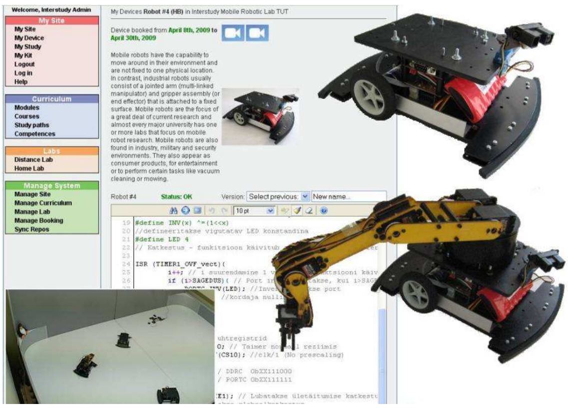

Fig. 4. DistanceLab web environment and mobile robots

Virtual Micro Controller Unit

One problem in education of micro controller technology is the need of (often) special hardware for labs, which are (in total costs) quite expensive. Also in the beginning of education micro controllers the chance of breaking them up is relatively high. So the logical conclusion was to develop a virtualized micro controller simulator environment (VMCU). For working in an educational environment and a desired with a high level of attractiveness to fascinate young people for this technology, it was quite important for system design to be web related; so it can be included into the DistanceLab as we have done with real hardware. Therefore the technologies appropriate for the development are limited. It was the idea to have the VMCU running in a platform, reachable with any common web browser. Another requirement set was to have the VMCU working with "normal" binary files, so common C programming language development software can be used for utilising the VMCU. Other framework condition concerns the cost of the system. It was planned to have it as least cost-expensive as possible and without any annual/returning fees for encouragement. For demonstrating and attractiveness purposes a graphical version of the controller must be realized; only textual output is not sufficient. The general behaviour of the VMCU should be comparable to real hardware in the HomeLab kit. Last condition concerns the DistanceLab; it was foreseen to have the

VMCU unit included into the DistanceLab environment. Therefore the use of programming languages to develop the whole system is somehow limited. The virtual version of the HomeLab kits is based on Avrora [16], [17] and Java. It is up to today a full functional, but virtual micro controller running in a web browser. It can be used for prototyping, simulating complex behaviour as well as for education purposes. The current development status is shown in Fig. 5. Currently the VMCU is used in Bochum for education of starting students in embedded programming.

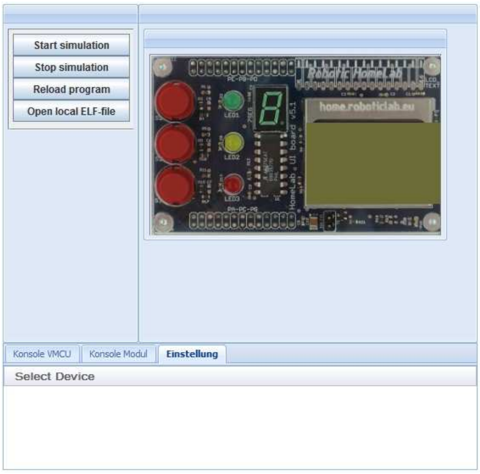

Fig. 5. Overview of Virtual MCU device and User Interface module

As the Avrora framework was chosen for the development, the programming language Java as a programming language was set. The developed package is known as *virtualmicroclab*. As the technology is Java and the fact that the system should be integrated into a web page, we can use inter applet communication for the system. The general approach is illustrated in Fig. 6.

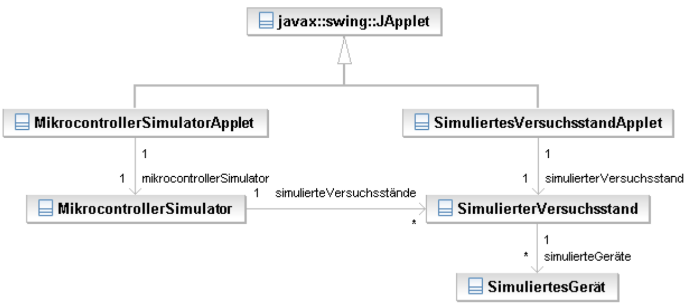

Fig. 6. Concept with applets

In current development status three VMCU units are reachable by the DistanceLab with different kinds of simulated modules, like 7-segment-display, LCD display and the in Fig. 5 illustrated User Interface module with additional components, like LEDs, buttons and an graphical LCD display. The VMCU supports full use of the HomeLab library and can be programmed like real hardware.

Network of Excellence - Robotic HomeLab Community

The Network of Excellence [11] is a website, hosting a lot of material, methodology and software for robotic studies. It is also called Robotic HomeLab Community and is a supporting system for utilization of HomeLab for users and teaching staff. The site includes material like examples, theory about components, overview of the hardware, overview of the software in several different languages. The website has a forum for discussions and wiki pages for user contributions. The site has a special section for the teachers, which includes the teacher training material, and most important – the exercise solutions and answers of revision questions. In the Robotic HomeLab Community the consortium intends to have all learning material and also the teaching methodologies directly accessible for interested learners and teachers. Ready to implement curriculum for the vocational schools are developed. The overall page is a multi-language system, with current translations to English, Estonian, French and German, where English is base language for all further translations. Next foreseen languages are Lithuanian, Russian and Turkish language. The strength of this website is the amount of supporting teaching aids, administrated from teachers and developers from different European countries, and therefore the influence of various cultures, level of knowledge or styles of teaching, which leads to a full set of supporting teaching material. New section is under the development where a set of learning situations, with full methodology will be available.

Practice - Case Study

The full concept is applied into practice in Estonia in three different level of education. All educational levels are using the same e-environment and hardware platform. The main difference is the amount of guided lectures and complexity of the embedded system, the learners working with.
In this chapter we are presenting shortly the main aspects of the all educational level and will present more detail the university level case study performed in Tallinn University of Technology, Estonia in 2011 spring semester.

In gymnasium level new state curriculum will applied officially in Estonia in 2011 where one of the major changes is a facultative branch where the school have to offer to pupils at least three of them. One of the branches is in natural sciences where robotics is one of the offered courses. Several schools have been started with the robotic course already 2-3 years ago and now have good experience to include the course into their general curriculum. The main technical aspect of teaching the robotics in Estonian general educational institutions is the use of micro controller based robotic learning kits. The first start with robotics is performed normally in primary school level, where Lego Mindstorm NXT kit is the hardware platform. This ensures rapid start and fast results which is very important to keep the motivation up for the robotic studies. Several standard Lego robotic solutions are built, used in competitions together with other schools which are performed during the autumn and spring holiday. In high school level (gymnasium) the next step is offered and robotic platform is changed to the Robotic HomeLab kit described in previous chapter. This is a logical step where the playground is moved from toys to more (close to) real systems. Graphical programming is replaced with C/C++ source code programming although the algorithm remains as a model of the system. In that way pupils learn that the system behaviour can be independent from the target physical system. However the main concept of robotics: sensor-control-actuator is already familiar and therefore easy to migrate to new platform. The content of practical projects is also integrated more into real life systems (e.g. intelligent control of the smart house). This two-step approach enables to start fast, without losing the motivation and reach the high knowledge in the end of gymnasium studies quite a low course volume.
One of the most important success factors of this experience is the continuous education process and support for the teachers. Even one may think that main obstacles would be the lack of money of buying the equipment or lack of interest among the pupils, it turned out that the major success factor is the local teacher motivation. Corresponding author has personal experience of helping to start the robotic course in more than 50 schools around Estonia and educating more than 80 teachers during past three years. The experience shows that motivated and innovative teacher, even with lack of professional skill in robotics, is the key factor of success in starting the robotics in the school. According to this conclusion the key factor of strategic planning of high school robotic curriculum is a teacher training and continuous support in any aspect related to robotic education.

The case study in vocational school includes around 10 different institutions where the robotics is a course of Mechatronics, Computer Science or Electronics curriculum. The main difference compared with high school study approach is that the content can be related with other parallel courses like electronics, logics, programming, etc. There is no need to start with Lego any more as the vocational students are already familiar the field they are selected for themselves. However the lack of knowledge of robotics is still a issue even with vocational schools students but may vary much of schools and their main speciality. Another main difference is the preparation of the teachers where continuous education is not so crucial but definitely needed for best results.

In university level the case study has been performed in two different target groups. One target group has been non-Mechatronic students (mechanical engineering students) and other Mechatronics bachelor students on the frame of Mechatronics project course. The second one is describe more detail.

Course setup

The course, named "Mechatronics project", is a half-semester course for Mechatronics students just before the diploma work. The main purpose of the course is to apply the basic knowledge acquired from the previous studies into the practice by designing and building an integrated Mechatronic system with limited time and budget. The work is done in groups and by following the basic project management process.

The whole course is described by the supervisors only with one graph using Mindmap technique. On the Fig. 7 the particular course setup in spring 2011 is demonstrated.

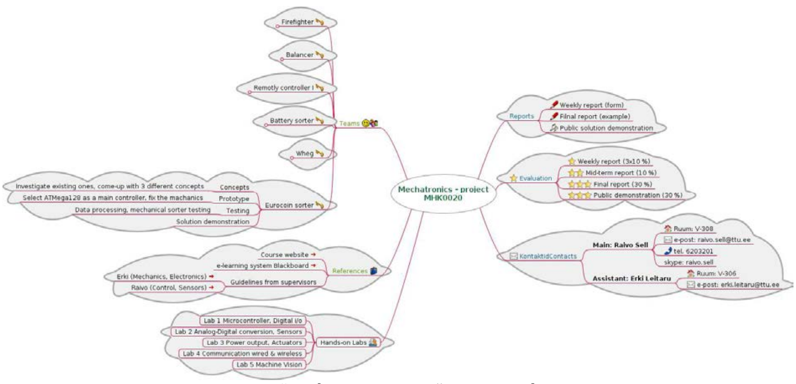

Fig. 7. "Mechatronics Project" course Mindmap

Equipment involved

The course is based on Robotic Learning & Teaching Concept described above and utilizes most of the aspects and resources the concept offers. First of all it uses Robotic HomeLab kits for the labs where students can perform the labs either in classroom or at home, depending on their favour. Same kit is used as a source of main controller and peripheral modules for later system development. Some extra components are usually needed and are heavily dependent of the group design decisions and current resources we can offer. Usually the additional components are construction material (aluminium sheets, plastic, fixings) and different, application specific sensors or motors. However by using same kits as for the labs it is possible to build the systems with very low additional cost.

Working process

The work starts of course with introduction where all rules and process are described, mainly based on Mindmap (Fig. 7) graph.

All labs are done in group work and one report is completed per group. On parallel with hands-on labs the groups have to design custom solution assigned to the group. The group specific task can be same for all groups (in case some robotic competition is the final target), different task per group or all groups are working with one big system dividing it into sub-systems. To ensure the continuous working the evaluation procedure is dispensed over the time of the course. Groups have to present weekly reports which are discussed and evaluated during the course meetings. The final report is composed directly to the web, into the HomeLab Kit Community project space and is directly available to supervisors and has also direct public accessibility. Student groups get initial help from supervisors to do the labs but it is intended that they will do the main work after short introduction without direct supervisor guidance. Important aspect of the course is the final public demo of the developed system. This motivates students to finalize the system and also make the robot with attractive outlook. The public demo is also important to keep the time frame solid because if the date is fixed and audience asked there is no way to postpone the finalization of the project. The experience is showed that students are happy and proud to present their work to public even if they afraid it on the beginning. This is the additional value to get some public presentation experience.

Conclusions

All described robotic study instances where using the same hardware platform and same study concept described in chapter above. Of course there are differences on focus points and in details but the general concept remain and has been proved in practice. In addition to the Estonia the concept is also successfully applied onto the study process in Germany in vocational school and universities of applied sciences.

The feedback for this case study is gathered from the students and also the supervisors experience is studied. By summarizing the feedback from students, most positive aspects were pointed out. Students were reporting to spend far more time to this particular course than expected in official curriculum, but the additional time was investigated not as it was required by supervisors but their own motivation was to improve the solution and get things working. The conclusions from students side was that this kind of concept of learning the mechatronics and robotics is more effective than they have experienced. And they resulted with great outcomes with very limited time and budget conditions. It may seem that the workload of the supervisor and assistant is very high, but in fact the Robotic HomeLab concept together with supporting e-environment lowered it significantly compared with previous experience before the implementation of this concept. The main conclusion and most important aspect is that the workload of supervisors is decreasing but the quality and outcome of the course for the students is increasing.

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F. Additional material

Listing F.1: Imported XML Schemata to LaaS LDL (part)

```
<?xml version="1.0" encoding="UTF-8"?>
[...]
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
 xmlns:dc="http://purl.org/dc/elements/1.1/"
 xmlns:dct="http://purl.org/dc/terms/"
 xmlns:dcm="http://purl.org/dc/dcmitype/"
 xmlns:dbpprop="http://dbpedia.org/property/"
 xmlns:foaf="http://xmlns.com/foaf/0.1/"
 xmlns:ims="http://www.imsglobal.org/xsd/imsafapnp_v2p0p2.xsd"
 xmlns:gpx="http://www.topografix.com/GPX/1/1"
 xmlns:wsdl="http://www.w3.org/2007/06/wsdl/wsdl20.xsd"
 xmlns:nsdl="http://ns.nsdl.org/schemas/nsdl_all/nsdl_all_v1.02.xsd"
 [...]
 targetNamespace="http://www.online-labs.eu/laas.xsd"
 elementFormDefault="qualified"
 attributeFormDefault="unqualified">
 [...]
</xs:schema>
```

Listing F.2: VMCU XML Schema based on LDL

```
[...]
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
 xmlns:laas="http://www.online-labs.eu/laas.xsd"
 [...]
 elementFormDefault="qualified"
 attributeFormDefault="unqualified">
[...]
 <xs:element name="simulationdevice">
  <xs:complexType>
   <xs:sequence>
    <xs:element ref="parameters"/>
    <xs:element ref="resources"/>
    <xs:sequence minOccurs="0">
     <xs:element ref="analogpins"/>
     <xs:element ref="outputpins"/>
    </xs:sequence>
    <xs:element ref="inputpins"/>
   </xs:sequence>
   <xs:attribute name="classfile" use="required"/>
   <xs:attribute name="type" type="xs:NCName"/>
  </xs:complexType>
 </xs:element>
 [...]
 <xs:element name="pin">
  <xs:complexType>
   <xs:attribute name="id" use="required" type="xs:integer"/>
   <xs:attribute name="initvalue" type="xs:boolean"/>
   <xs:attribute name="name" use="required" type="xs:NCName"/>
  </xs:complexType>
 </xs:element>
[...]
</xs:schema>
```

Listing F.3: Description of an HD44780 Display

```
[...]
<simulationdevice type="LCD_HD44780">
[...]
  <resources>
    <resource name="displayFont" type="font" path="BODisplay.ttf" />
    <resource name="displayBackground" type="image" path="LCD.jpg" />
  </resources>
[...]
  <inputpins>
    <pin name="E"   id="0"/>
    <pin name="RW"  id="1"/>
    <pin name="RS"  id="2"/>
    <pin name="DB0" id="3"/>
    <pin name="DB1" id="4"/>
    <pin name="DB2" id="5"/>
    <pin name="DB3" id="6"/>
    <pin name="DB4" id="7"/>
    <pin name="DB5" id="8"/>
    <pin name="DB6" id="9"/>
    <pin name="DB7" id="10"/>
  </inputpins>
</simulationdevice>
[...]
```

Name	**Developer**	**Extensible**	**System Requirements**	**Price**	**Link**
AVIDICY AVR Compiler	Forest Electronics	No	Windows	$\geq$ 75 USD	[107]
AVR Simulator IDE	Oshonsoftware	No	Windows	29 EUR	[108]
BASCOM-AVR	MCS Electronics	No	Windows	89 EUR	[109]
CrossWorks	Rowley Associates	No	Windows, Linux, Mac, Solaris	300 USD	[110]
IAR Embedded Workbench for Atmel AVR	IAR Systems	No	Windows	price to be asked	[111]
Proteus	Labcenter Electronics	No	Windows	$>$ 200 EUR	[112]

Table F.1.: Commercial, closed source MCU simulators available on the market

Name	Developer	Open Source/extendable	System Requirements	Annotations	Link
Algorithm builder	Gennady Gromov	No	Windows 95/98/2000/ NT/ME/XP	Simulator Freeware, development environment, Shareware	[113]
AVR Studio	Atmel	No, but own plug ins are possible	Windows NT/2000/XP /Vista	development environment.	[114]
Avrora	UCLA Compilers Group	Yes	Java Virtual Machine		[115]
GNU AVR Simulator	S. Uvarov, O. Tykhomyrov	Yes	Linux mit Motiv program library	no maintenance any more	[116]
imavr	Sergey Gulchuk	Source code available	Unix/Linux	old project, not maintenance any more	[117]
simavr	Michael Pollet	Yes	Linux	Development just started	[118]
SimulaAVRxx	Klaus Rudolph et al.	Yes	Linux	Development just started	[119]
SimulAVR (NonGNU)	Diverse Personen	Yes	Linux, Windows	Used in WinAVR	[119]
VMLab	Advanced Micro Tools	No, somehow possible	Windows, Linux mit WINE	was commercial before	[120]

Table F.2.: Free MCU simulator environments on the market

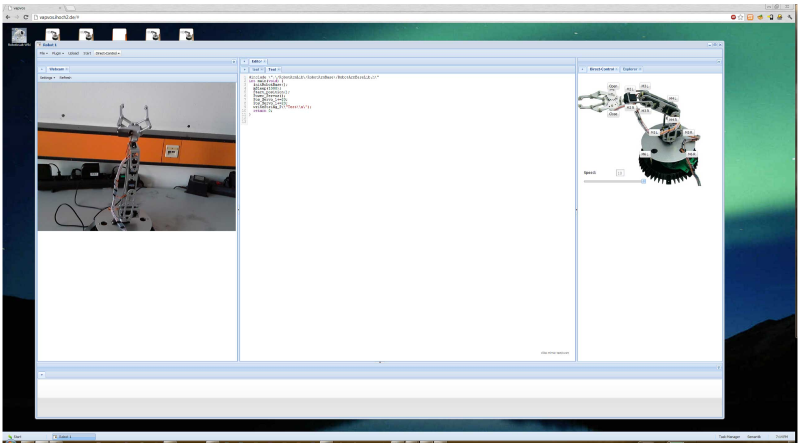

Figure F.1.: Robot Arm Environment in the DistanceLab 2.0

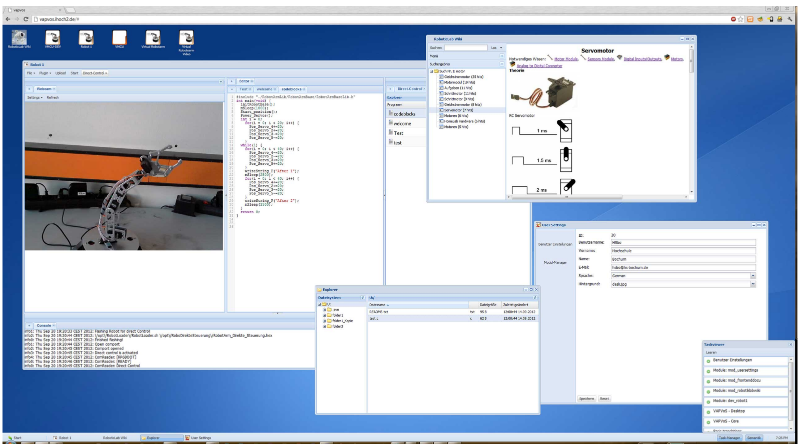

Figure F.2.: Robot Arm Environment, with Network of Excellence Integration, and User settings window in the DistanceLab 2.0

G. References

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I. Kokkuvõte

PIDEV tehnoloogiate areng ja innovatsioon on 21. sajandi inseneeria ja tööstuse peamised tunnused. Sellest tulenevalt on tungiv vajadus rakendada üleeuroopalist teadusasutuste koostööd ja harida noori insenere kooskõlas tehnoloogia arenguga. Tingituna tehnoloogia kiirest arengust seisavad uurimisasutused, ülikoolid ja insenerikutset andvad õppeasutused vastamisi olulise väljakutsega - tuleb pidevalt uuendada oma laborite seadmeparki, metoodikaid ja õppekavu. Nende tingimuste täitmiseks on vaja lahendada mitmed põhimõttelised küsimused, milleks on tehnilise suunitlusega uurimis- ja arendustöö inseneriõppe valdkonnas. Esmane probleem on ajakohaste seadmete kättesaadavus ja ligipääsetavus kõigile asjasse puutuvatele isikutele (nt uurimisrühma liikmed, tudengid, ettevõtte esindajad jt) ja seda sõltumata erinevatest traditsioonilistest piirangutest, nagu ruum, aeg ja juhi kättesaadavus. Teine tavaline probleem on kallite laborite ja laboriseadmete rahastamine, eriti juhul, kui kallist aparatuuri on vaja suures mahus ja kindlal ajal (nt andmemahukate uurimisprotsesside raames või ülikoolis mingil semestril põhiõppes). Kolmas ja tihti ignoreeritud probleem on nüüdisaegse veebitehnoloogia rakendamine praktilises õppes, eriti inseneriõppes. Loetletud probleemide üks lahendusviis on pakkuda veebitehnoloogiapõhist kaugjuurdepääsu seadmetele koos e-õppega kombineeritud õppega, mida toetavad Interneti-põhised laborid ja kaugeksperimentide võimalus. Antud uurimistöö käigus pakutakse nende probleemide jaoks välja terviklikke ning uudseid lahendusi, liidestades ning integreerides kaug- ja virtuaallaborid seal oleva seadmestikuga ühte terviklikku süsteemi koos vastava rakendusmetoodikaga. Need eesmärgid on saavutatud järgnevate töös käsitletud põhiteemade lahendustega:

(i) Holistiline ehk terviklik töövahendite komplekt reaalajas ligipääsetavate kaug- ja virtuaallaborit liidestamiseks ning andmevahetuseks uudse väljatöötatud baastehnoloogia kaudu - 'Laboratory as a Service' (LaaS), tõlkes - laboratoorium kui teenus. Tegemist on uudse lähenemisega, mis rakendab veebitehnoloogiat, võimaldades kauglaboreid jagada erinevate institutsioonide vahel.

(ii) Uudne meetod Interneti kaudu ligipääsetavate laborite unifitseeritud liidestamiseks, sõltumata labori tehnoloogilisest baasist ja algsetest liidestest, kasutades LDL-keelt 'Lab Description Language', tõlkes - labori kirjelduskeel. LDL kasutab XML-i kirjelduskeelt. Väljatöötatud meetodit võib lisaks ülikooli laboritele kasutada ka tööstuslikes lahendustes, näiteks rakendades ettevõttes kontseptsiooni 'Factories of the Future'.

(iii) Jätkusuutlik terviklik raamlahendus insenerihariduse projektipõhiseks e-õppeks, mis on fokuseeritud mehhatroonika, arvutiteaduse ja tootearenduse erialadele.

Loetletud metoodikad ja lahendused on piloteeritud kui kontseptsiooni prototüübid järgnevate reaalsete rakendustena:

(i) Web 2.0 tehnoloogial põhinev Interneti-rakendus 'DistanceLab 2.0', mis on kauglaborite portaal.

(ii) Virtuaalne veebipõhine sidussüsteem 'Virtual Micro Controller Unit', mille moodulid on liidestatud töö raames välja töötatud LDL-keele abil.

(iii) Reaalsed integreeritud kaug- ja virtuaallaborid mehhatroonika ja arvutiteaduse valdkonna joaks, mis kasutavad väljatöötatud LDL-i liidestamiskeelt ja LaaS-i tehnoloogiat.

Kõik rakendused on piloteeritud ja hinnatud Euroopa Liidu projektide koostöö raames mitmetes Euroopa ülikoolides ja väikeettevõtetes. Piloteerimise ja testi tulemused ning teadus- ja arendustööd on publitseeritud mitmetes teadusajakirjades ja esitatud konverentsidel, mis on loetletud töö lisas.

Doktoritöö peatükis 1.2.1 on määratletud viis peamist probleemi, millele on leitud lahendused. Lahendused on võetud kokku peatükkides 2, 3 ja 4, mis on täiendatud lisatud publikatsioonidega. Töö lisades olevad publikatsioonid kajastavad antud teemaga seotud uurimis- ja arendustöid.

Peatükk 2 "Holistic blended framework for Research and Education in Mechatronics and Computer Science"kirjeldab raamistikku ja metoodikat, kuidas tehnilist väljatöötlust rakendada insenerihariduses ja teadustöö kontekstis, käsitledes seda eelkõige mehhatroonika ja arvutiteaduste valdkonnas. Tehniline kontseptsioon (peatükk 2.2) seob omavahel didaktilise kontseptsiooni ja tehnilised lahendused, mis on robootika kodulaborid, virtuaalne mikrokontroller ja kauglaborid ning LDL (labori kirjelduskeel). Peatükk lõpeb diskussiooniga (peatükk 2.4), kuidas sobivad omavahel didaktiline ja tehniline kontseptsioon. Peatüki esimeses osas (peatükk 2.1) on antud ülevaade state-of-art-lahendustest, mis on käesoleval hetkel inseneeria e-õppes kõige kaugemale arenenud. Selle peatüki kontseptsioone käsitletakse eraldi veel töö lisades olevates artiklites: Paper A ja Paper C ning lisaks Paper E.

Peatükk 3 käsitleb kontseptsioone "Laboratory as a Service (LaaS)"ja "Lab Description Language (LDL)". Peatükk algab üldiste laborite ja seadmete jagamise ajakohaste lahenduste (state-of-art) analüüsiga (peatükk 3.1), millele järgneb ülevaade doktoritöö raames välja töötatud uudsest LaaS-i ja LDL-i kontseptsioonist, mis võimaldab vahendada kaug- ja virtuaallaboreid (peatükk 3.3).

Peatükk 4 annab ülevaate uudsest virtuaallahendusest - 'Virtual Micro Controller Unit (VMCU)' alates VMCU raamistikust, mis baseerub Avrora süsteemil (peatükk 4.5), kuni üleüldise kontseptsioonini, mis liidestab selle veebipõhise virtuaalse sidussüsteemi raamistikule. VMCU raamistikku kajastatakse täiendavalt artiklites Paper B ja Paper A.

Üldistatud doktoritöö struktuuri, uurimistöö temaatika ja selle rakenduse võib klassifitseerida järgmiselt:

- Väljaarendatud unikaalne tehniline lahendus
  - Laboratooriumi kui teenuse kontseptsioon - Laboratory as a Service concept (LaaS)
  - Labori kirjelduskeel - Lab Description Language (LDL)
  - Virtuaalne mikrokontroller - Virtual Micro Controller Unit (VMCU)
  - Robootika kodulabori komplektid
  - Kauglabori platvorm

- Loodud uus didaktiline lahendus
  - Õppematerjal
  - Teadmisvõrgustik - Network of Excellence (NoE)

Eesmärgid ja lahendused Võttes kokku töö alguses formuleeritud uurimistöö eesmärgid, saab need seostada väljaarendatud lahendustega järgnevalt:

(i) Loodud formaalne kirjelduskeel kaug- ja virtuaallaborite spetsifikatsioonile tehnilises keskkonnas, milles LDL kui XML-i dialekt pakub stabiilse viisi laborite kirjelduseks ja labori serverite andmevahetuseks. LDL-i rakendatakse virtuaalse mikrokontrolleri perifeeriaseadme ja kontrolleri vaheliste virtuaalsete viikude kirjeldamisel.

(ii) Loodud sobiv kommunikatsiooniprotokoll Interneti kaudu ligipääsetavate laborite vahendamiseks ja identifitseerida vajalikud tehnoloogiad ning vahendid integreerimaks kaug- ja virtuaallaborid e-õppe protsessi. LaaS-i kontseptsioon koos LDL-i kirjelduse ettepanekuga formuleeriti EL-i 7. raamprogrammi IP projektiks ning anti sisse jaanuaris 2012. Projekt sai positiivse hinnangu ja on käesoleval hetkel staatuses 'enabled for funding'. Tuginedes LDL-i kirjeldusele, on kommunikatsioon LaaS-i kontseptsioonis realiseeritud läbi veebiteenuste, mis põhinevad WSDL-il ja SOAP-il, võimaldades liidestada olemasolevaid laboreid ja seadmeid. LaaS-i töövahendite komplekt pakub lihtsalt plug-and-play-lahendust integreerimaks uusi laboreid teenusega LaaS Provider. Üleüldine LaaS-i kontseptsioon on terviklik lahendus organisatsioonide ressursside (laboriseadmete) jagamise toetamiseks.

(iii) Väljaarendatud ja rakendatud raamkontseptsioon virtuaalsete sidussüsteemide loomiseks. Virtuaalne mikrokontroller (VMCU) pakub töökindla raamistiku virtuaalsetele seadmetele. Näidetena ja lahenduse tõestusena on realiseeritud virtuaalsed moodulid: 'Robot Arm' ja 'User Interface Board'. VMCU on veebipõhine modulaarne raamistik, mis kasutab LDL-keelt ja avatud lähtekoodiga tarkvara.

(iv) Koostatud terviklik e-õppe kontseptsioon, rakendades kaug- ja virtuaallaboreid inseneerihariduses. Kontseptsioon 'Holistic Blended Framework for Research and Education in Mechatronics and Computer Science' töötati välja ja realiseeriti osaliselt erinevate EL-i projektide toel, kus töö autoril oli kandev roll. Tulemused on rakendatud erinevatel haridustasemetel peamiselt Saksamaal ja Eestis.

(v) Uurimistöö tehnilise raamistiku sobivust reaalses situatsioonis ning selle seost e-õppe kontseptsiooniga on juba rakendatud ja selle rakenduse kohta on saadud positiivseid hinnanguid. See on saavutatud järgmiste EL-i tehnoloogiasiirete rakendusprojektidega: Interstudy, Autostudy, MoRobE, MeCFuture, VAPVos ja ViReal.

Märksõnad

kauglabor, virtuaallabor, kaugõpe, e-õpe, mikrokontroller, robootika

J. Abstract

WITHIN the frame of the author's studies, a holistic framework for remote and virtual labs was researched, proposed and implemented. Continuous evolution of existing technologies and rapidly occurring innovations are the characteristics of 21th century engineering industry. Thus, there is an urgent need to realize pan-European research institutions collaboration and educate young engineers to keep up with this progress. Research institutions, universities and other higher educational institutions have to meet this challenge to keep up with the high pace of technological advancements in industry by being up to date with research equipment, educational concepts and curricula.

To satisfy this demand there are several issues to be solved in advance, especially for R&D and engineering education.

The first one is an insufficient availability of high value and large equipment for all relevant persons (for instance for research team members, engineering students, industry persons, etc.), due to resource issues. The second point is the funding problem for these kind of labs, in particular for very expensive ones or those that are required in high quantity (in the frame of data intensive research processes or in basic studies in universities). The third issue is the inadequate implementation of technology-enhanced learning in the practice-oriented parts of engineering education.

One starting point to conquer these problems is to offer web based technologies for remote access to equipment and eLearning in blended learning education with the assistance of internet-accessible labs and experiments. The proposed concept in this thesis is to conquer these problems with a comprehensive approach, introducing a novel and innovative framework for mediating, interfacing and integrating remote and virtual labs including all devices and equipment belonging to those labs.

The following methodologies and frameworks have been developed in the frame of present thesis:

(i) A comprehensive toolkit for interfacing and mediating online accessible virtual and remote labs through core technology approaches, named 'Laboratory as a Service' (LaaS). This solution breaks technology barriers by offering lab sharing and the application of eLearning technologies without institutional borders.

(ii) A novel method for the unified integration of internet-accessible labs by utilizing the 'Lab description Language' (LDL), independent of their base technology and interfaces. This approach is based on XML and can also be applied in the context of industrial applications, like the 'Factories of the Future' scheme.

(iii) A sustained holistic framework for the education of engineering students in Mechatronics and Computer Sciences, focusing on project-based learning.

The previously presented concepts and tools are implemented as a proof of concept, featuring:

(i) A Web 2.0 rich internet application, denoted as 'DistanceLab 2.0', being a provider platform

(ii) A virtual web-based embedded system, called 'Virtual Micro Controller Unit', of which interfacing of the modules is realized through LDL.

(iii) Diverse integrated remote and virtual labs in the area of Mechatronics and Computer Sciences, built upon LDL and LaaS technologies were realized.

All approaches have been evaluated and tested in ongoing cooperation between several European research and educational institutions, as well as SMEs. The presented publications in the Annex reflect this research and development.

Section 1.2 introduces the five over-spanning objectives to be solved in the doctoral thesis, that were covered in the subsequent chapters 2, 4 and 3, supplemented by appropriate publications. The publications presented in the Annex reflect this research and development. An overview of how the researched components fit together is illustrated in fig. 5.1. Three levels, 'Research', 'Development' and 'Proof of Concept', are presented with all the components described in this thesis shown in one of these levels.

Chapter 2 describes the "Holistic blended framework for Research and Education in Mechatronics and Computer Science", divided up into the *technical concept* (section 2.2) including the Robotic HomeLab kit, VMCU and Distance Lab and LDL and the *didactical concept*, ending with a discussion in section 2.4 about how the two concepts fit together. This chapter is completed by a state-of-the-art discussion (see section 2.1) of the application of eLearning in engineering education. In addition the concept is discussed in Paper A (p. 65) & Paper C (p. 92), with additional content in Paper E (p. 107).

The part about the VMCU introduces a novel concept in chapter 4, ranging from the VMCU framework to the overall concept with a focus on changes to the Avrora system (section 4.5) to enhance it to be a web-based virtual embedded system framework. Furthermore, the VMCU framework is covered by Paper B (p. 101) and also in Paper A.

The concepts of "Laboratory as a Service" and the "Lab Description Language" were covered in chapter 3, with a full state-of-the-art analysis about common ways of remote lab sharing in section 3.1, followed by an introduction to the LDL and LaaS approaches for mediating remote and virtual labs in section 3.3.

By giving the whole content of the thesis a unifying structure, the researched and implemented features can be classified into:

- **technical approaches**
  - Laboratory as a Service concept (LaaS)
  - Lab Description Language (LDL)
  - Virtual Micro Controller Unit (VMCU)

  - Robotic HomeLab kits
  - DistanceLab platform
- and **didactical approaches**
  - Teaching and learning material
  - Network of Excellence (NoE)

Objectives and solutions Taking a closer look at the original intended objectives, these can now be compared with the solutions presented in the thesis.

(i) A formal description language for the specification of remote and virtual labs in engineering science was researched and implemented. LDL as an XML dialect offers a proven and stable way for describing and mediating labs with a distance lab server. An implementation of LDL for embedded devices is utilized for the VMCU to describe virtual pin connections between controller and associated devices.

(ii) A proper infrastructure for mediating internet-accessible labs was researched and implemented. This research was accompanied by the identification and implementation of necessary technologies and tools for interfacing and integrating remote and virtual labs into blended and distance learning processes. The LaaS concept with LDL was submitted to the EC in January 2012 for an IP project and got positive feedback, being enabled for funding. Based upon LDL description the communication in LaaS is realized through web services based on WSDL and SOAP to interface with existing labs and control them, due to the small overhead produced. The LaaS toolkit offers an easy plug-and-play solution to integrate new labs to the LaaS Provider. The overall LaaS concept is a comprehensive solution for the envisaged cross-institutional lab sharing.

(iii) A framework concept for the creation of virtual embedded system devices was researched and implemented. The VMCU offers a solid framework for virtual embedded systems. The virtual modules 'Robot Arm' and 'User Interface Board' are implemented applications which prove the concept.

The VMCU is a web-based, modular framework using LDL and open source software.

(iv) A holistic blended learning concept by utilizing remote and virtual labs in education was researched and implemented. The 'Holistic blended framework for Research and Education in Mechatronics and Computer Science' was researched and developed during several European projects and applied into daily education.

(v) The researched technical framework, was developed and evaluated as a proof-of-concept by utilizing virtual embedded devices and transferring this implementation to a real-world scenario, by connecting it to the blended learning concept. This goal has been achieved in the frame of the European projects Interstudy, Autostudy, MoRobE, MeCFuture, Netlab and ViReal.

Keywords

remote labs, distance labs, virtual labs, distance learning, eLearning

K. Zusammenfassung

Im Rahmen dieser Doktorarbeit ist ein ganzheitliches Rahmenwerk für ferngesteuerte und virtuelle Labore erforscht, projektiert und implementiert worden. Die stetige Weiterentwicklung existierender Technologien und zügig auftretende Innovationszyklen sind charakteristisch für das 21. Jh. im Bereich der Ingenieurwissenschaften und der dazugehörigen Industrien. Aus diesem Grund besteht eine große Notwendigkeit angehende Ingenieure zielgerichtet zu unterrichten um nicht den Anschluss an diesen Fortschritt zu verpassen. Universitäten und andere höhere Bildungseinrichtungen müssen diese Herausforderung annehmen um mit der hohen Geschwindigkeit des technologischen Fortschritts in der Industrie Schritt halten zu können. Dies kann nur geschehen, wenn die Lehrkonzepte und curricularen Inhalte laufend angepasst und verbessert werden. Um diesem Bedarf gerecht werden zu können, sind zunächst einige Probleme zu lösen, vor allem im Bereich der Ingenieurswissenschaften. Das erste Problem ist die unzureichende Verfügbarkeit von hochwertiger Laborausstattung für Ingenieursstudenten. Der zweite Punkt betrifft die Finanzierung dieser Ausstattung, vor allem bei sehr teuren oder solchen, die in einer hohen Anzahl benötigt werden (vor allem im Grundstudium). Dritter Aspekt ist die unzureichende Umsetzung und der mangelhafte Einsatz von technologiebasierten Lehrkonzepten im praktischen Teil der Ingenieursausbildung. Erster Anknüpfungspunkt um diese Probleme anzugehen ist es, den Lernprozess mit computergestütztem Lernen oder gemischten Lehransätzen unter Zuhilfenahme von über das Internet ferngesteuerten Laboren anzureichern. Das Konzept, welches im Rahmen dieser Arbeit vorgestellt wird, setzt dem Problem einen ganzheitlichen Ansatz gegenüber. Kern dieser Doktorarbeit ist ein neues und innovatives Rahmenwerk für die Vermittlung, Verbindung und Integration von ferngesteuerten und virtuellen Laboren. Diese Ansätze finden sich wieder in den nachfolgenden Kapiteln, in denen die nun genannten Inhalte behandelt werden:

(i) ein umfassender Werkzeugsatz für die Verbindung und Vermittlung von online basierten, virtuellen und ferngesteuerten Laboren durch eine Basistechnologie, die 'Laboratory as a Service' (LaaS) genannt wird. Diese Lösung durchbricht technologische Barrieren, indem sie die Möglichkeit schafft, Laborequipment und computergestütztes Lernen über die Grenzen von Bildungseinrichtungen hinweg anzubieten.

(ii) eine neue Methode für die einheitliche Integration von Internet basierten Laboren durch den Einsatz von 'Lab Description Language' (LDL). Der Ansatz basiert auf XML und kann auch für industrielle Applikationen, wie zum Beispiel im Bereich ferngesteuerter Fabriken eingesetzt werden.

(iii) ein nachhaltiges und ganzheitliches Rahmenwerk für die Ausbildung von Ingenieuren in Mechatronik und Informatik, mit dem Fokus auf projektbasierten Lehr- und Lehrkonzepten.

Die aufgezeigten Inhalte sind als ein Machbarkeitsnachweis, mit den folgenden Schwerpunkten umgesetzt worden:

(i) Entwicklung einer reichhaltige Internetanwendung, bezeichnet als 'DistanceLab 2.0', welche als eine Anbieterplattform ausgelegt ist.

(ii) Erforschung und Entwicklung eines virtuellen, web-basiertes eingebetteten Systems ('Virtual Micro Controller Unit')

(iii) Entwicklung diverser integrierter ferngesteuerter und virtueller Labore aus den Bereichen Mechatronik und Informatik, die auf den Technologien LDL und LaaS aufbauen.

Alle Ansätze wurden evaluiert und getestet in fortlaufenden Kooperation mit mehreren europäischen Forschungs- und Bildungseinrichtungen und KMUs.

Stichwörter

Ferngesteuerte Labore, Virtuelle Labore, Fernstudium, computergestütztes Lernen

L. Curriculum Vitae

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A-Level	Städt. Stiftsgymnasium Xanten, 2001
Dipl-Ing. (FH)	Bochum University of Applied Sciences, 2007
M.Sc.	Tallinn University of Technology, 2009

4. Language Skills	
German	mother tongue
English	advanced level

5. Career	
Since 2007	Bochum University of Applied Sciences

Scientific Work

Review work

- IEEE Transactions on Education
- Computer Applications in Engineering Education
- 7th. International DAAAM Baltic Conference
  Industrial Engineering, 22 - 24th April 2010, Tallinn, Estonia

Scientific projects

- Interstudy
  Advanced E-Curricula and Mobile Tools for Interdisciplinary Modular Study
  started 02.2007, 24 month
- Autostudy
  Modularization of the automotive study process by e-environment
  LLP-LdV/TOI/2008/EE/005, started 10.2008, 18 month
- MoRobE
  Modern Shared Robotic Environment
  LLP-LdV/TOI/2009/DE/147/252, started 09.2009, 24 month
- Containerlagersysteme
  Effizienzsteigerung von Logistikclustern durch die Entwicklung eines Systems zur modalen Nutzung von ISO-Containern [...], AZ-Nr. 280447002
  started 04.2009, 36 month
- VAPVoS
  Virtual Academy Platform for Vocational Schools
  LLP-LdV/TOI/2011/DE/147/355, started 09.2011, 24 month
- NetLab
  Learning Situations in Embedded System StudyLab
  LLP-LdV/TOI/2011/DE/147/355, started 09.2011, 24 month

- Circum Mare Balticum
  NOE 10/017, International Bureau of the BMBF,
  started 04.2011, 18 month

Dissertations defended at Tallinn University of Technology on Mechanical and Instrumental Engineering

1. Jakob Kübarsepp. Steel-Bonded Hardmetals. 1992.
2. Jakub Kõo. Determination of Residual Stresses in Coatings & Coated Parts. 1994.
3. Mart Tamre. Tribocharacteristics of Journal Bearings Unlocated Axis. 1995.
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5. Jüri Pirso. Titanium and Chromium Carbide Based Cermets. 1996.
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15. Toivo Tähemaa. Assurance of Synergy and Competitive Dependability at Non-Safety-Critical Mechatronics Systems design. 2002.
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bined Heat Transfer Enhancement Technique in Gas-Heated Channels. 2005.

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of Collaborative SME-s. 2007.

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