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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. 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.

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

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 controller and microprocessors). 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 field. In the presented Integrated Concept for Embedded System Study we are utilizing the AVR technology for the HomeLab Kit assisted also by additional hardware.

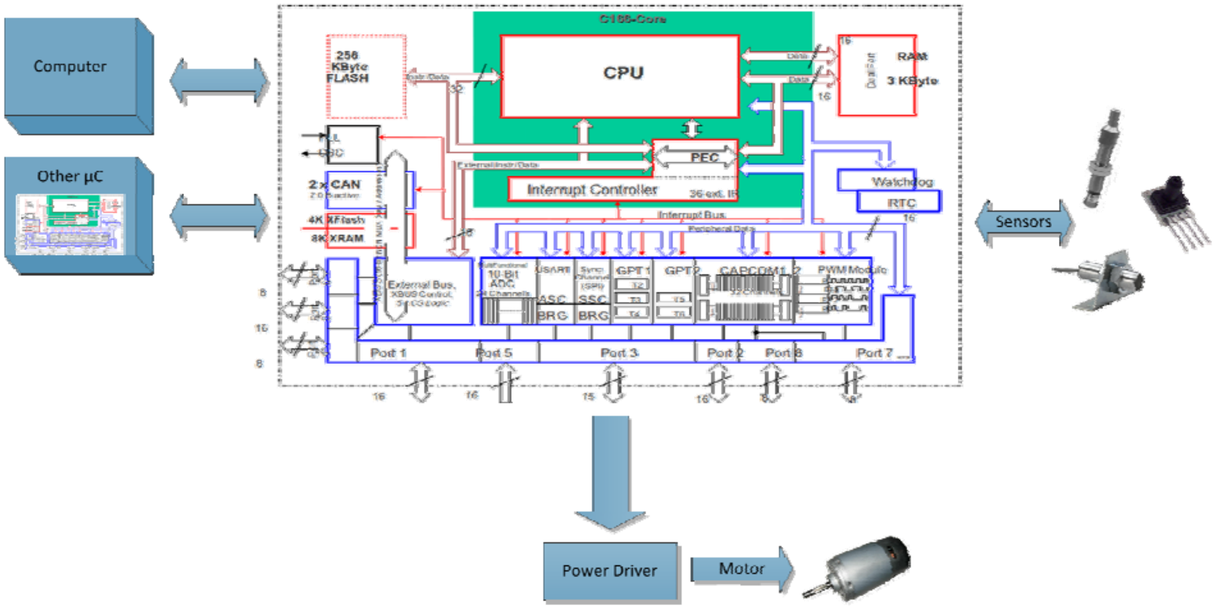

Fig. 1. Example of embedded system

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. 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 is also included to the concept; we are including international collaboration and multilingual cooperation as one of our main goals. 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 also 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.

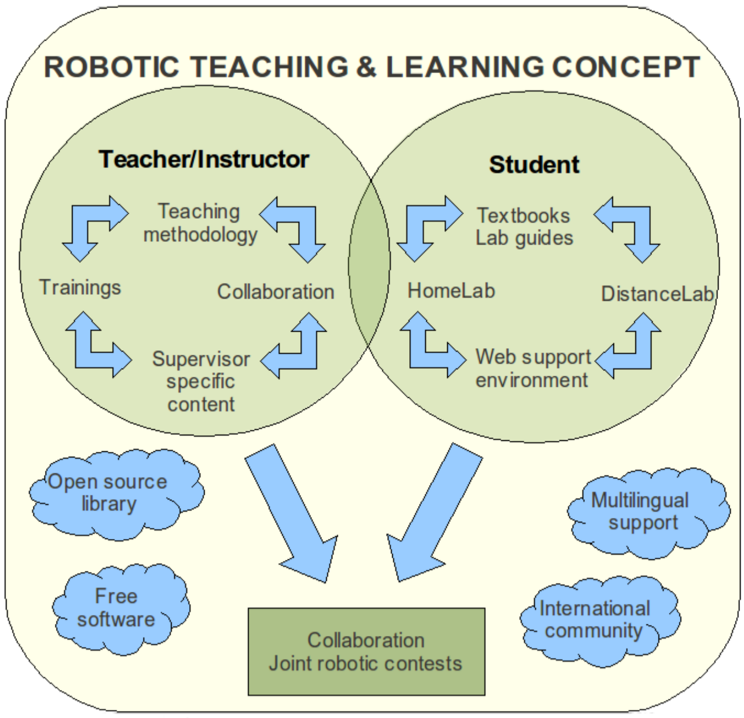

Fig. 2. Integrated Study Concept - Robotic Teaching & Learning Concept

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, USB and 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 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 labs 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.

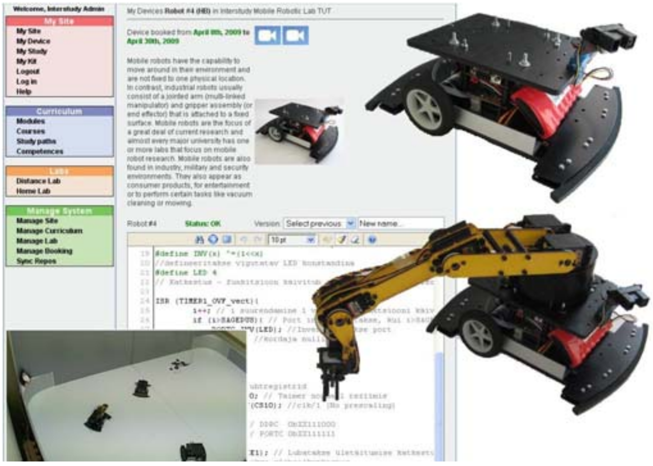

Fig. 4. DistanceLab web environment and mobile robots

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 Distance Lab 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 Distance Lab; it was foreseen to have the VMCU unit included into the Interstudy Distance Lab 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 figure 5. Currently the VMCU is used in Bochum for education of starting students in embedded programming.

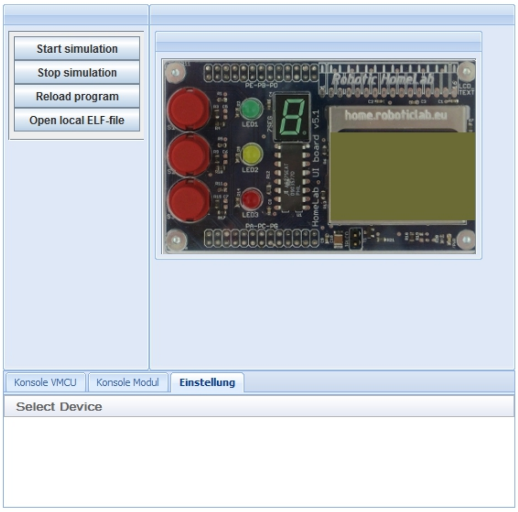

Fig. 5. Overview of Virtual MCU

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.

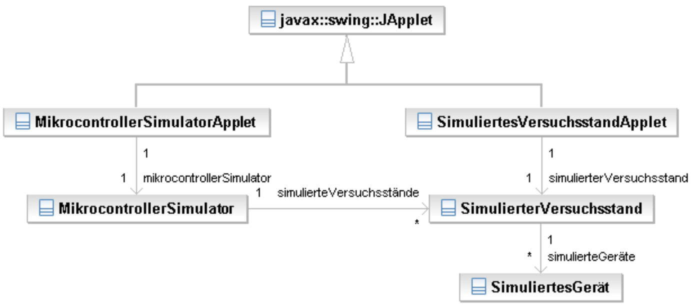

Fig. 6. Concept with applets

In current development status three VMCU units are reachable by the Distance Lab with different kinds of simulated modules, like 7-segment-display, LCD display and the in fig. 5 illustrated Study Board 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, as well as 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, with current translations to English, Estonian, French and German, where English is base language for all further translations. Next foreseen language 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, 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.

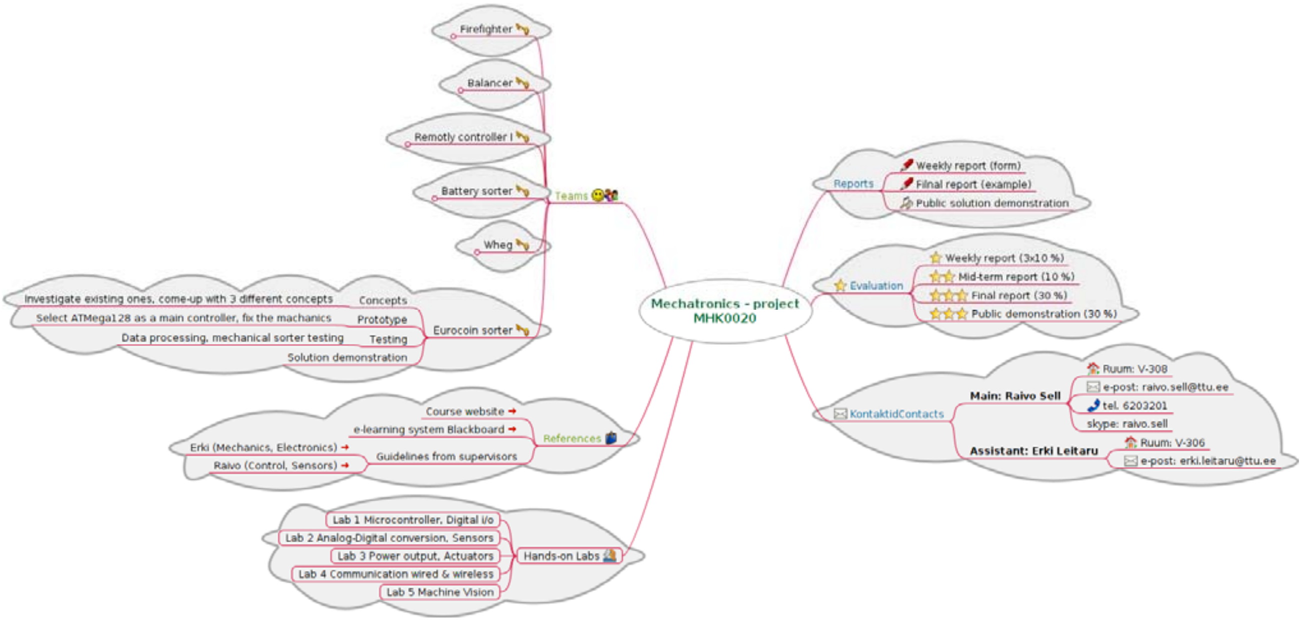

Fig. 7. “Mechatronics Project” course Mindmap

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 completion is the final target), different task per group or all groups are working with one big system dividing it to sub-systems. In this case study different small robot tasks were assigned. 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 in course. The final report is composed directly to the web, into the HomeLab kit community project space and is directly available to supervisors and also public accessibly. 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 by them. Important aspect of the course is the final public demo of the developed system. This motivates students to finalize the system and also make them 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.

Results and conclusions

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 are 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.

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.

Acknowledgements

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