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A MODULAR APPROACH TO EXPERIMENTAL LEARNING AND FAST PROTOTYPE DESIGN OF MECHATRONIC SYSTEMS
– INTRODUCING THE MECHATRONIC LEARNING CONCEPT

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Abstract

Mechatronics can be defined as a thematic academic subject, with a functional legitimacy. One method of meeting the requirements of the functional legitimacy is to stress the aspects of experimental learning and fast prototype design in mechatronics education. This paper introduces the idea of the Mechatronic Learning Concept (MLC) as a structured modular approach to integrate fast prototype design in education.

The MLC consists of inter-compatible modules exemplifying various technologies, philosophies and protocols. The aim of this paper is to present the possibilities in terms of mechatronics education and prototype design that has arisen from this development, together with results from a first set of experiments of teaching mechatronics using this concept. These educational experiments were undertaken during the period from November 2001 to June 2002, and involved 150 students in their third and fourth year in the mechatronics undergraduate program at KTH.

The conclusions of these first experiments show that giving students constant access to advanced and appropriate experimental equipment creates a more favorable educational setting which affects the students’ attitudes towards their experimental learning positively. Further, the results also show that with relatively complex mechatronics systems, the MLC greatly facilitates a fast prototype design.

Keywords: Mechatronics, Experimental learning, Design education, Prototypes, Fast prototyping

1. Introduction

In mechatronics education it is advantageous if students are allowed to design and build real products, and particularly if these products are flexible in a way that encourages innovative and creative work [1, 2, 3]. This research explores the changes in students’ learning styles that occur when given access to equipment that encourages experiments and enables the design of intelligent products, including fully functional prototypes, such as robots or autonomous vehicles.

1.1 The Mechatronic Learning Concept

The Mechatronic Learning Concept was initiated at KTH Machine Design in 1998, and after several years of development has reached maturity where the concept is used in most mechatronics courses given by KTH as well as at several other universities. The original idea was to develop a modularized system, which combined constitutes a Mechatronic system, for education in mechatronics [4]. Examples of different types of modules are: microprocessor modules, real-time operating system modules, motion control modules, and communication modules. In principle all modules are compatible; a student should be able to choose a microprocessor ranging from simpler 8-bits to more advanced 32-bits, connect a motion control module with the appropriate mechanics, program the microprocessor in one of several possible languages, using one of several possible real time operating systems and finally make the mechatronic system communicate with the user/surroundings with one of several possible communicating technologies, either wirelessly or with cables. Examples of more recent technologies that has been integrated into the concept are a TCP/IP implementation on 16- and 32-bits microprocessors which enables the microprocessors to communicate via the internet, Bluetooth modules which enables mechatronic systems to inter-communicate wirelessly, for example between mechatronic robots, and sensor- and actuator modules that facilitates the design of robots and other motion control applications.

With a focus on related academic disciplines, the MLC can also be used in the disciplines that mechatronics is built upon. To facilitate learning in control theory for example, a system can be built with a mechanical process controlled by a discreet controller, and a real time operating system could both facilitate the analysis of the process and also enable relevant experiments for courses in computer programming [5]. The MLC differs from similar projects due to the fact that the modules are made for a large number of students, with a low-cost profile; basically the experimental equipment should not be more expensive than the course literature, with the aim that all students taking a course in mechatronics should be able to get access to a complete set, during the entire course, for use either at home or on campus.

This paper introduces the design concept; the modules and the possibilities in terms of mechatronics education and prototype design that has arisen from this development, together with the results from experiments in teaching mechatronics using this concept. These educational experiments were performed during the period from November 2001 to June 2002, and involved 150 students in their third and fourth year in the mechatronics undergraduate program at KTH.

2. Prototype design using the Mechatronic Learning Concept

The Mechatronic Learning Concept can be seen as a system consisting of three groups of modules; hardware-, software- and educational modules. The educational modules consists typically of material such as literature, exercises, web based educational platforms, which primarily are developed for a specific course or a specific technology. An example of this is educational modules developed to facilitate learning of communication in and between embedded systems via CAN (Controller Area Network). In this case, the educational modules consist of literature, exercises and projects related to this specific communications technology, together with examples adapted for the hardware modules. Since this article however focuses on prototype design the educational modules will not be described further. In the following the hardware- and software modules will be referred to as “the modules”.

2.1 Microprocessor modules

The microprocessor modules all have three identical interfaces: power supply, RS232-connector for communication with a PC, and a bus for connecting other modules. Depending on the different microprocessors configuration, each module is either equipped with RAM, EEPROM or both, to fulfill the requirement that each module should be able to run sufficiently large programs and store the code in non-volatile memory. To facilitate debugging, each module should be able to execute from either RAM or EEPROM. Depending on the various microprocessors used, the microprocessor module are also equipped with reset functions, switches for altering configurations, and other options, for example, inputs for alternative A/D reference voltage.

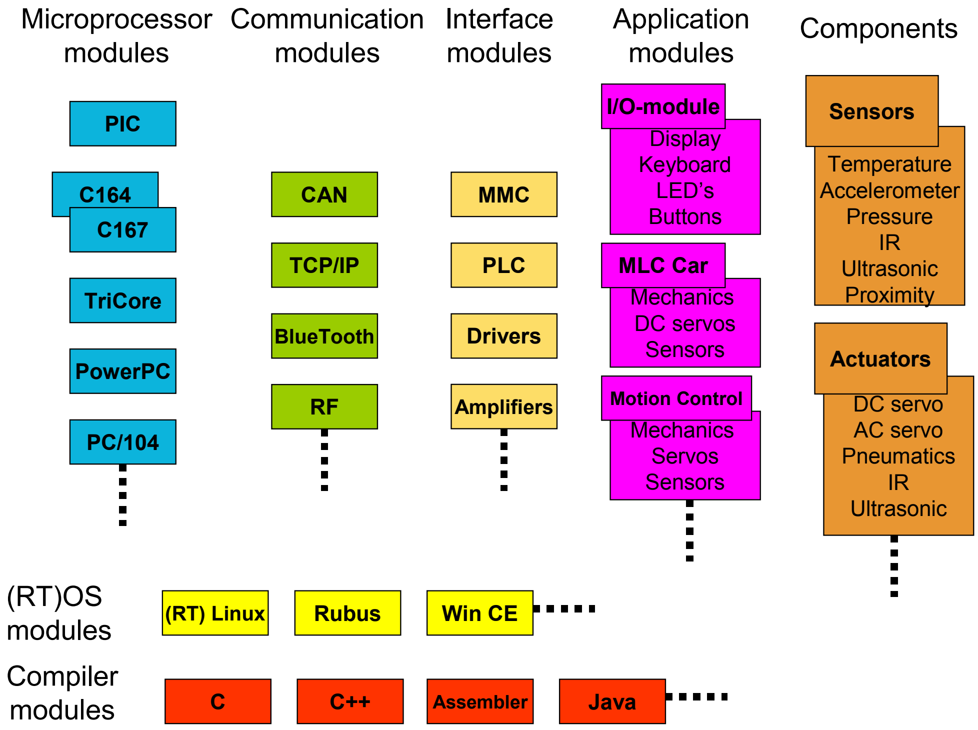

Figure 1. Examples of MLC modules [4]

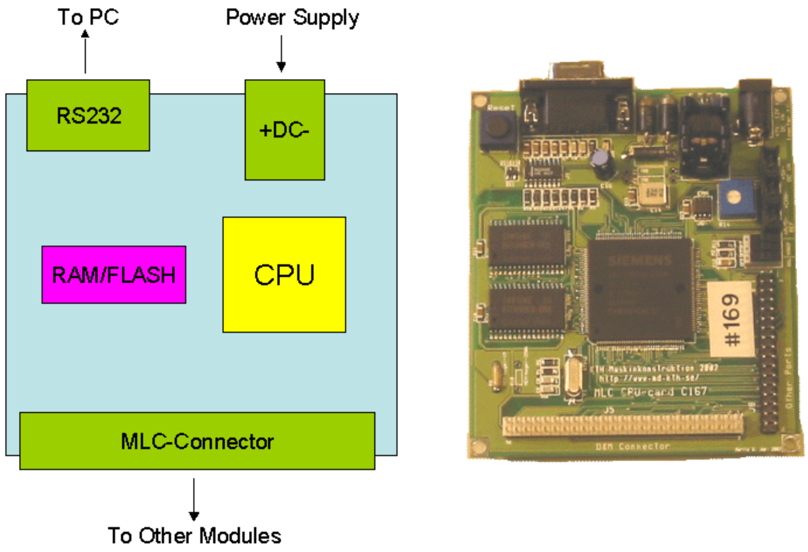

Figure 2. A general schematic of a microprocessor module (left) together with a photo of a microprocessor module; the Infineon C167CS module (right). The dimensions of the module are 70 x 80 mm.

2.2 Communication modules

Four different communications modules have been developed and are integrated into the MLC: The CAN module enables communication between two or more MLC systems, or between a MLC system and an existing CAN network. The TCP/IP module enables any MLC system to communicate with other MLC systems directly or via the Internet. The TCP/IP module is equipped with a complete TCP/IP stack including a simple web server. The two wireless modules, the Bluetooth module and the RF module enable wireless communication between two or more MLC systems.

2.3 Interface modules

The interface modules are used either as interface to products and systems outside the MLC, or as amplifiers for sensors and drivers for actuators. An example of an interface to an external product is the MMC (Multi Media Card) reader: a module that can be used to save large amounts of data for later transfer to a host PC. The PLC module is used as interface towards systems with other logical levels such as servo amplifiers, pneumatic actuators and other motion control hardware.

2.4 Application modules

The application modules are used to provide students with a complete system, together with a microprocessor module and software modules. Two examples of this are an I/O module and the MLC car. The I/O module contains a display, a keyboard, switches, potentiometers, DC motor driver circuit and encoder inputs. This card can be used to develop and debug systems, and act as an interface towards the user. The MLC car is an example of sensors and actuators integrated into the mechanics of a small vehicle. The car is equipped with two servomotors, one encoder on each wheel, proximity sensors, reflex detectors and bumper switches.

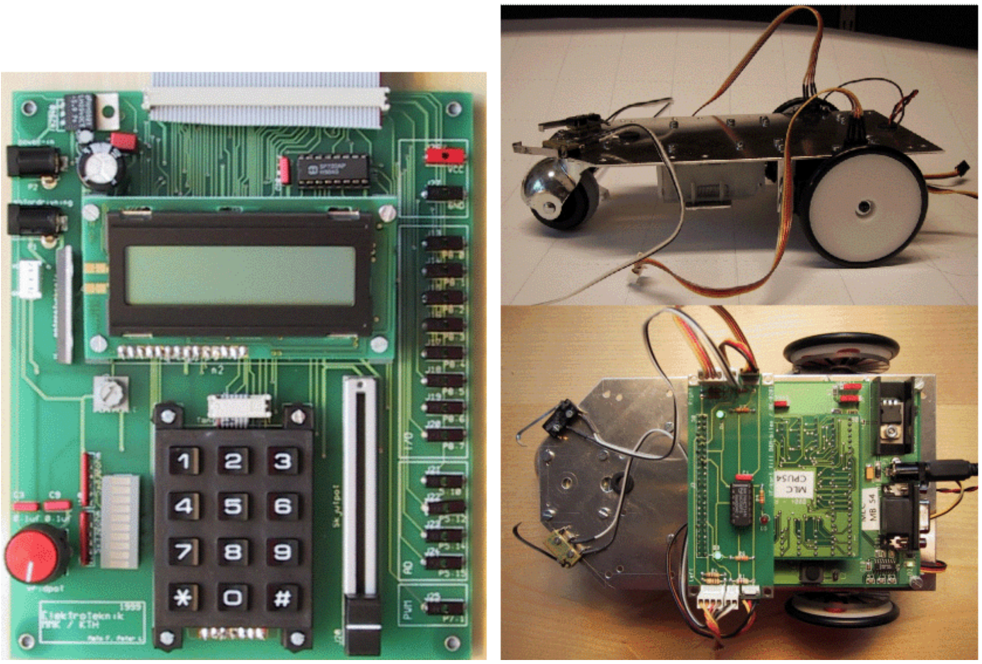

Figure 3. Examples of two application modules: An I/O module and the MLC car.

2.5 Components

To further make the MLC more flexible a basic kit of compatible components, mainly sensors and actuators, has been chosen. Examples of these are: Infrared transmitters and receivers, ultrasonic transmitters and receivers, gas sensors, daylight sensors, speakers and microphones, pressure sensors, accelerometers, temperature sensors, rotary sensors and proximity sensors.

2.6 Operating system and compiler modules

In the case of operating system modules the compatibility issue is difficult to maintain, and the microprocessor modules in the MLC are only compatible with one or two operating system modules. Today three different operating system modules are used: Linux and Windows CE for the PC/104 and PowerPC modules, and Rubus for the C16x and the TriCore modules.

Also for the compiler modules the choice is limited. For reasons of scalability and cost in general, the strategy is to have a choice between free software and commercial products. The GNU C compiler is ported to several of the microprocessors used in the microprocessor modules, which together with the GNU debugger provides a development environment for C and C++. In some cases commercial compilers and debuggers is the only choice, and an agreement has been made with commercial developers to provide evaluative or full versions of their compilers and debuggers to the MLC. The Java compiler module today is available only to the largest microprocessor modules, with the 32-bits microprocessors, but the intention is to provide this module to the modules with 16-bits microprocessors as well.

2.7 Development of MLC modules

There are several commercially available modules on the market, particularly microprocessor modules, interface modules and application modules. The advantage of using these modules is the cost of initial development, with the disadvantage that modifications have to be made to maintain the concept of compatibility. One of the fundamental ideas behind the MLC is the idea of fast prototype design, which is facilitated by a modular database-based design process. This approach is also advantageous in the case of advanced courses where the students design completely new modules, where this design can be supported by accumulated knowledge and skill within the faculty, as well as documentation and experience from previous design projects. Figure 4 shows the five steps involved in the development of MLC modules.

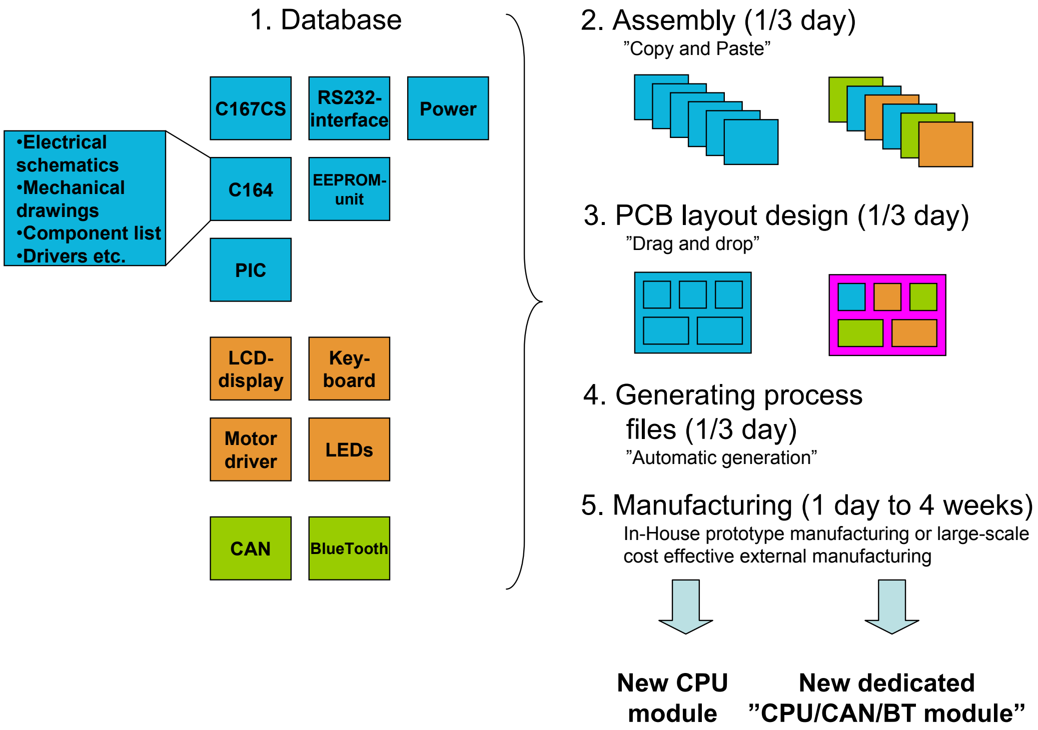

Figure 4. Development of new MLC modules - Fast prototype design. Numbers are related to text below.

1. The database contains electrical schematics, mechanical drawings, lists of necessary components and software drivers for all components included in the MLC. This information is mainly based on the manufacturer's datasheets and previous prototypes developed within the MLC.
2. Since the schematics for all components are available in the database the assembly process enables the designer to combine components, or modules, from different types of MLC modules. The figure above shows the assembly of an ordinary microprocessor module and of a special dedicated system with all modules integrated on one circuit board.
3. In the case of developing new MLC-modules the third step is a straightforward design process, but in the case of dedicated systems this design is done in with the aim of the final product, for example integrated into the complete systems design.
4. From the database information and the previous two steps the manufacturing files are automatically generated.
5. In educational projects there is a great advantage if the prototypes can be manufactured fast, and for this purpose a simpler prototype printed circuit board (PCB) can be manufactured in any laboratory by using standard procedures for PCB development. For the development of professional prototype boards or large series of boards, as well as component soldering, external manufacturing might be necessary.

3. Teaching prototype design of mechatronic systems

The purpose of the MLC is to facilitate experimental learning in mechatronics. In this section this issue will be illustrated in two modes, which both are represented by two experiments undertaken at KTH Machine Design during the period between November 2001 and June 2002.

3.1 The relation between experimental learning and prototype design

In the title of this paper two key phrases are used: experimental learning and fast prototype design. The relation between these aspects of learning has been described previously [6] and is connected to the characteristic identity of the subject of mechatronics [1, 7]. Mechatronics is a subject with a thematic identity, in contrast to most traditional academic subjects that has a disciplinary identity. In short this is due to the fact that mechatronics is a cross disciplinary subject, that still lacks of a well established identity in the greater surrounding, and hence is often described by examples or themes, for example by a comparison with the theme of robotics. Further, mechatronics relies on the concept of synergy, primarily synergy between mechanical engineering, electrical engineering and control theory, and the thematic identity can be illustrated by this synergistic added value that is gained when combining knowledge in these fields [1, 5, 7].

A direct consequence of the thematic identity is the functional legitimacy of mechatronics. The functional legitimacy is connected to the students' abilities, that the education is legitimized not by a formal competence in relation to a particular curriculum but rather to the students' abilities to design mechatronic products and systems. The functional legitimacy can also be extrapolated into the faculties' selection of the subject: which aspects of mechatronics that the faculty should teach and what the students should learn.

In short, the results from this didactical analysis are that education in mechatronics should be supported by experimental learning. Mechatronics cannot be learnt by reading only textbooks.

The subject of mechatronics is learnt by studying Mechatronic products and systems, and primarily, by designing mechatronic products [4]. So, to summarize, there is a direct line from learning mechatronics through experimental learning to prototype design of Mechatronic systems. Therefore, in the following sections of this paper, focus will be held on the use of the MLC in prototype design, as a method to acquire knowledge in mechatronics.

3.2 The basic course experiment – The Lab in Your Pocket

The first experiment was done within a basic course in mechatronics, and will be referred to as the basic course experiment, and the second was done in an advanced course in mechatronics, and will be referred to as the advanced course experiment. The difference between these experiments are related to which modules were used, and how the modules were used: in the basic course mechatronic systems were designed using the existing MLC modules, and in the advanced course the existing MLC modules were used together with new dedicated MLC modules; developed by the students with a specific configuration, for a specific purpose.

This basic course, which aims at giving students an introduction to mechatronics, as well as basic knowledge in microprocessor systems, is traditionally a course with extensive experimental work. Typically a student spends between one and two weeks (40-80 hrs) in the laboratory during a period of seven weeks. In short the aim with this experiment was to give each student, within a focus group, his or her individual set of laboratory equipment required to fulfill all experimental work in the course, for the student to decide when, where and how to perform the experiments. In the basic course all students could choose from a list of projects, where all projects were aiming at designing a functional prototype of a mechatronic product. Examples of projects and products are:

- Distributed motion control
- Quick-dial for telephones
- Ultrasonic range-finder

For this basic course a focus group of 30 students were chosen to participate in the experiment. These 30 students all got their individual set of experimental equipment, from the set of MLC modules, and were compared to a reference group of 70 students who were chosen not to participate. These 70 students followed the same course, but were referred to stationary traditional laboratory equipment. The method of collecting data from this experiment was primarily by interviews with students in the focus groups, together with comparisons between the outcomes of the projects, meaning the products designed.

For this article, only the significant differences between students using the MLC and students following the traditional course are mentioned. These differences, as registered in the analysis of the experiment, are:

- Students using the MLC primarily appreciated the flexibility of the concept, meaning that an individual student could choose when, where and how to undertake the experiments within the course.
- Students using the MLC tended to spend more time using the MLC compared to the time the reference students used the laboratory facilities provided by the faculty. The reasons stated were primarily to achieve a better grade or due to increased curiosity.
- The MLC students could choose from a large number of projects, or prototypes to build, and the interest for designing the prototypes was high, which is verified by the fact that a

considerable number of students came up with their own ideas for prototypes. In comparison, most students in the reference group defined their project as a regular course delivery, and showed considerably less enthusiasm or creative work.

3.3 The advanced course experiment – The Boston Tea Party project

The advanced course experiment has been introduced previously [4], and for this paper a brief description will be given together with the significant results drawn from this experiment. The course studied was problem-based and project-organized, spanning over a period of seven months. A group of twelve students was given a task to design a complete mechatronic system, in this case a portable medical research unit consisting of five embedded processors, 20 sensors and 60 actuators. The five embedded processors should intercommunicate via the CAN protocol, as well as wirelessly with a stationary node [8].

As a method for development, the students were given access to the MLC, and instructed to use the existing modules as far as possible. The functionality not provided by the MLC was required to be designed by the student team.

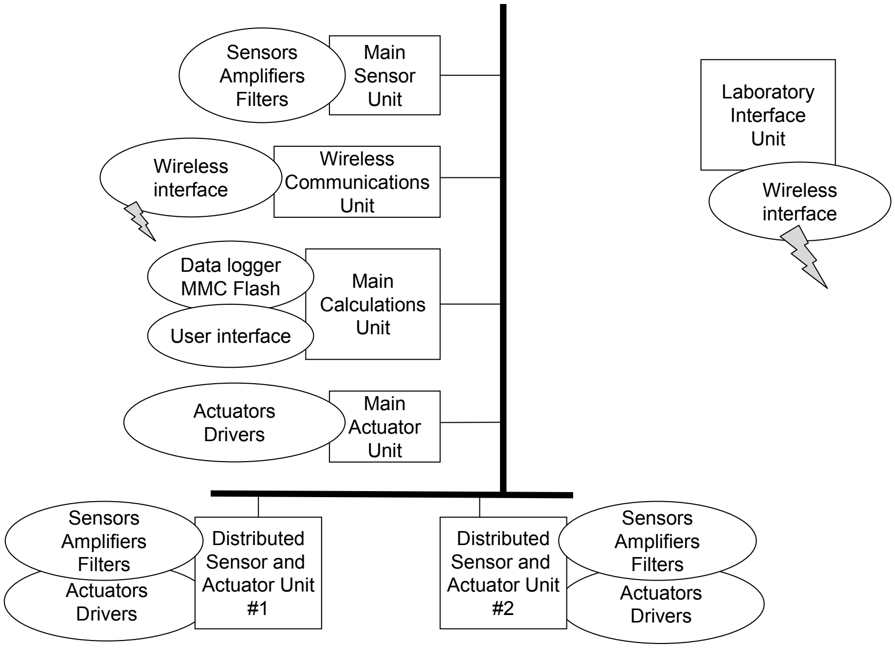

Figure 5. A system view of the Boston Tea Party project, for a fast prototype development using the MLC

When analyzing the project the following conclusions could be drawn:

- By using the MLC a rough prototype could easily be assembled within a few weeks to serve as a platform for deciding on necessary specifications.
- By using the MLC philosophy the project was divided into subsystems, such as data logging, sensor sampling etc. Each of these subsystems could be developed simultaneously by sub teams of students, for later assembly into a final system.
- At the beginning of this project neither the Data logger (MMC Flash) nor the Wireless Interface module existed. These modules were developed by small teams of students, and integrated into the MLC to provide this functionality. Since modules such as microprocessor modules, I/O modules etc. already existed this task could fairly easily be done.

The third point above illustrates the idea of the MLC as a structured method of accumulating knowledge. These modules were not available at the start of the project, but in the next course, for the next team of students, these are available, and the new team can focus on expanding the concept further.

When comparing the option of not using the MLC, the task to design the medical device could either be done by designing the entire system from scratch, which would require years instead of months. Else, the system could be designed by commercially available modules, such as Starter-kits, but also in this case the process would be considerably more difficult and time consuming since these modules by default not are inter-compatible, as well as more expensive. When, for example comparing the manufacturing cost of one microprocessor module, or a Bluetooth module with a similar commercially available module, the cost is roughly one tenth compared to the commercial modules (€ 50 compared to € 500).

4. Discussion and results

The first experiment was primarily done within the framework of a basic course in Microcomputer systems, an introductory course in the mechatronics undergraduate program. The aim of this course is to give students a broad knowledge of microprocessor-based systems, good skills in programming a microprocessor for a smaller embedded system, as well as experience in the design of a fully functional prototype. To reach this aim, a project-organized approach is applied where each student is required to design a fully functional prototype based on the modules developed within the Mechatronic Learning Concept. The results from this experiment conclude that the flexibility and modularity of the MLC enables the design of a large number of educational projects, with open-ended solutions. The size and relative low price of the modules also enables manufacturing in large series at a low cost, which in this experiment enabled the faculty to provide 30 students with a personal set, which created a favorable educational setting which affected the students' attitudes towards their experimental learning positively.

The results are based on a comparative study where the data is gathered in interviews, by questionnaires and by independent analysis of the students achieved results in terms of test results and final projects, i.e. the mechatronic systems designed by the students. In a comparison between students following a traditional educational setting and students engaged in the MLC, the conclusions are that the MLC students tend to choose an attitude towards their experiments where the students start experimenting earlier on in the course, spend more time experimenting, choose more advanced project designs, and choose a more independent attitude towards the faculty and a more flexible approach to the problems given.

In the second experiment, the idea of using the MLC in more complex prototype designs was tested within an advanced course in mechatronics. The purpose of the test was to investigate whether the educational process of designing a complex multi-processor based medical research device could be facilitated by using the MLC. The conclusions are that, from an educational point of view, the educational process benefited primarily from the fact that the MLC provided a platform for prototype design where a fast prototype could be assembled within a few weeks. Another important aspect is the idea of accumulated knowledge, or concept of structured assembly of previous projects and prototypes. The process of designing the medical research device could benefit from previous projects, as well as deliver functional modules to following projects.

5. Acknowledgements

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