A New Robotics Laboratory for Interdisciplinary Mechatronic Education

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Abstract. This paper presents a new robotic lab at the IPEK-Institute of Product Engineering at the faculty of mechanical engineering. The focus of the lab are the improvement of mechatronic education by teaching interdisciplinary technical capabilities as well as the training of social and communication skills. The development process of an autonomous mobile robot platform serves as a realistic training scenario in student teams. The paper shows the structure and the applied methods of the lab in the context of a comprehensive approach of teaching mechatronics. It describes the tasks the students have to solve and presents the experiences and findings of the lab which took place for the first time in the summer of 2010.

Keywords: mechatronic education, robotic platform, teaching concept

1 Introduction

Mechatronics, as a blend among software, electrical and mechanical engineering, is an important part of today's products and therefore plays a significant role in teaching at universities. At IPEK-Institute of Product Engineering mechatronics is characterized by its development process. This includes the close connection of different domains from the early development activities and not just as an addition of mechanics, electrical engineering and software.

Thus the development of mechatronic systems requires strong social and communication skills as the development process mostly takes place in interdisciplinary teams. Because of the complexity of mechatronic systems, familiarity with knowledge management methods is also mandatory for a successful development process. Those key qualifications can't be taught by lectures alone.

Therefore the IPEK offers a new robotic laboratory. It serves as an elective subject for the specializations Advanced Mechatronics, Automation Technology, Development and Construction, Information Technology, Cognitive Systems, Mechatronics and Robotics (diploma) and as an optional or additional subject for bachelor and master students.

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2 Education at IPEK – KaLeP

2.1 Overview

The IPEK offers several courses for students in the basic study period and the advanced study period. The courses reach from general mechanical design courses for up to 750 students down to specialised course on different subjects for small groups of students. The following list shows the courses of IPEK that have a special focus on mechatronics.

- Lecture: “Introduction to Mechatronics” (120 students), together with the Institute of Applied Computer Science (AIA) and the Institute of Engineering Mechanics (ITM)
- Lecture: “Product development of mechatronic systems” (30 students)
- Lab: “Mechatronic laboratory” (25 students)

The educational approach of the IPEK can be summarized by the term “KaLeP” (Karlsruhe Education Model for Product Development) see fig. 1. An important aspect of the KaLeP approach is the effort to generate a realistic development environment for the education of students [1]. This means for example that the basic machine design courses are accompanied by workshops where all students (approximately 750) are divided into groups of five students each and have to design a technical product over the semester. This practical teamwork is an important educational aspect because the students learn to use their theoretical knowledge and gain important social skills in a “real” development environment.

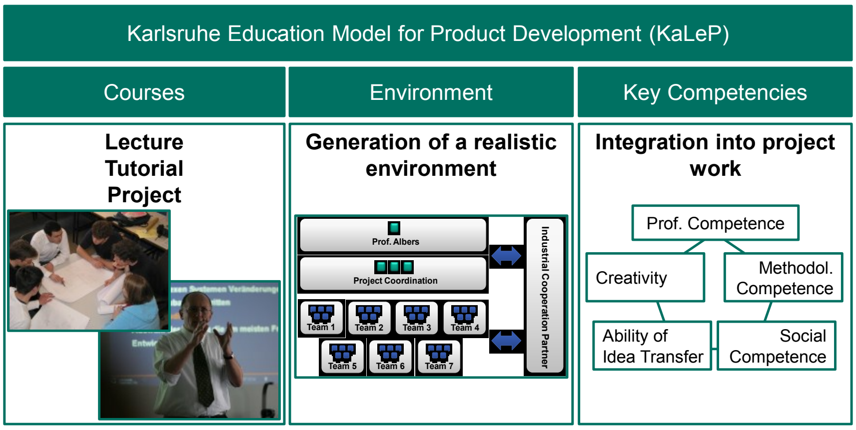

Fig.1. overview over the KaLeP

In this context, the new robotic laboratory is intended to offer a realistic development task with the special focus on a mechatronic system and is complementary to the other mechatronic courses and labs that are currently offered at IPEK.

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2.2 Motivation and Goals for Mechatronic Education

Since today almost every new technical product has a mechatronic character, mechatronic education is an important issue for students with a mechanical engineering background. Especially the general design processes and methods of electronic and software components are fields that are often disregarded in a classical mechanical engineering education.

The goal of the mechatronic education is to improve the understanding of complex technical systems and to enable the students to successfully develop mechatronic systems. Therefore the improvement of communication and social skills in the context of teams with a diverse educational background is very important. The education has to show the interplay of technical systems from the three domains of mechatronic: mechanical engineering, electrical engineering and computer science.

The mechatronic education should teach theoretical and practical knowledge for each of the technical disciplines to every student. This is important to boost the understanding of the students for the special advantages and problems that result from combining these fields and helps them to anticipate how their own work could affect their colleagues. To achieve this understanding the students need insights into the methodology and the tools of all the three domains.

Therefore students with a mechanical engineering background are confronted witch practical tasks like developing a control system and implementing it on a microcontroller as well as the design and layout of a circuit board.

3. Mechatronics and Robotics at IPEK

In mechatronics and robotics the IPEK has experience in different fields of research and education. Research subject at the institute are for example entire “vehicle in the loop” test benches for the automotive industry [2] or new assembling system for offshore wind energy plants [3].

Especially in the context of the Collaborative Research Center 588, the IPEK has gathered a lot of experience in designing humanoid robotic systems since 2001 [4]. In this project IPEK is mainly responsible for the design, manufacturing and assembly of the robots of the ARMAR series. The robots ARMAR III (a) and III (b) are shown in fig. 2. This Research Center where many students are involved either in the context of a thesis or as paid student workers has shown us that robotic systems are very fascinating for many students. Additionally robotic systems cover all the mechatronic fields and it possible to build a system at a scale and complexity that is suited for a one semester lab.

All this led to the task of developing small robotic systems for the new lab.

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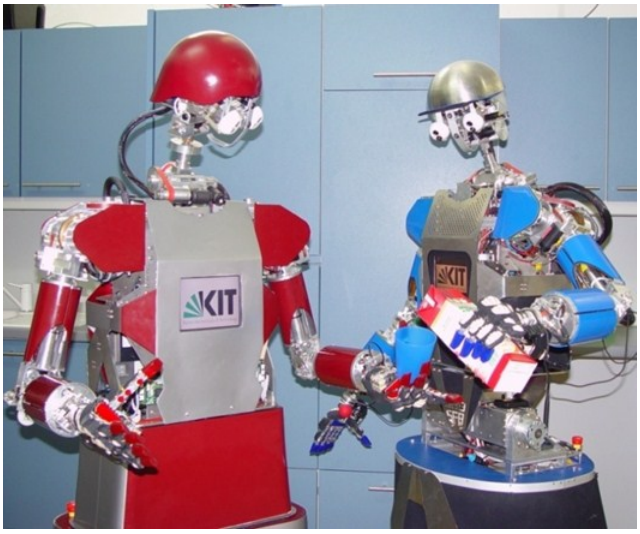

Fig. 2. The robots ARMAR III (b) (left) and III (a) (right)

4. The new Mechatronic Lab "Mobile Robotic Systems"

4.1 Overview

This new lab teaches the practical use and transfer of theoretical contents as well as important soft skills with the help of a typical mechatronic system. The goal is that the students undergo the entire development process of a mobile robot system that is capable to detect a wall and to drive along it while keeping a defined distance. The entire development process follows the V-model for the methodic design of mechatronic systems according to VDI-guideline 2206 [5].

For the lab the 20 Students are divided in five groups at four students. Each of the groups has to develop one robot. The robot has to be designed and assembled. The electronic parts have to be developed and partially manufactured and the control systems and software have to be designed and implemented.

Learning objective of this lab are practical, interdisciplinary engineering tasks. The students who mostly have a mechanical engineering background are supposed to gain knowledge in the fields of electronics and computer science as well as practical skills in the field of etching circuit boards and equipping them with electronic components.

At the beginning of the lab one session is reserved for a general introduction and for theoretical lessons regarding the different tools the students will be using during the lab. This is an important part because it ensures that all students have the foundations that are necessary for the lab.

Additionally to the technical aspects of the lab, the students also learn important competences like project management, communication skills and the ability to work in a team. This is especially important for successful mechatronic development processes since they mostly take place in interdisciplinary teams.

4.2 Boundary Conditions

Due to time limitations some specifications for the robot are given in advance. One afternoon a week two trained graduate students and one academic assistant from IPEK offer their assistance and give the students the chance to ask questions on specific problems. Attendance is only compulsory for the students when a deadline is reached. The aim of this lab is not only to teach programming skill but also to get familiar with widely used software-tools in the field of robotics respectively embedded systems. Additionally the layout and manufacturing of electrical circuits is also part of the lab. Therefore we do not use "off-the-shelf" robotic kits like e.g. Lego Mindstorms like presented in [6, 7].

The basic architecture of the robot is given in fig. 3. It consists of a holonomic platform where electronic components and sensors have to be integrated. The students have to design the mechanic platform, choose the sensors and place them on the frame.

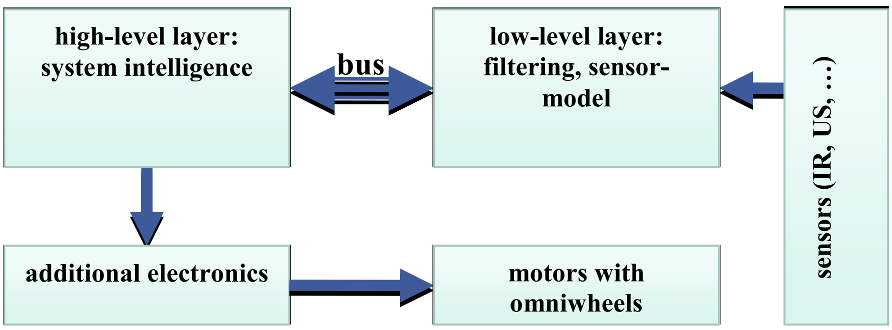

Fig. 3. The basic architecture of the robot

The basic control architecture is also given. It consists of an AVR microcontroller board for the sensor data acquisition and processing, an Infineon board for the control system and one board for the motor control.

The AVR- and the Infineon microcontroller boards are standard commercial evaluation boards and the students have to design, layout, manufacture and equip the motor driver board.

4.3 Tasks

Out of the main task of building and programming the robot as well as the given boundary conditions respectively specifications, four particular subtasks can be defined that are presented in the following:

1. Development of the closed loop control system using Matlab/Simulink
2. Implementation of sensor data acquisition, preprocessing and transmission on the AVR microcontroller
3. Implementation of the control system on the Infineon microcontroller
4. Development of an electronic board for the motor drivers

Since most of the students have a mechanical engineering background, the focus of the lab is specifically on the other mechatronic domains to fill a gap in the mechatronic education for mechanical engineers. Because of this reason, a special building set is used for the robot structure and therefore no mechanical manufacturing is necessary. This way the students are able to solve this task as a group in a short amount of time.

Development of a Closed Loop Control System using Matlab/Simulink.
The design of the control system includes tasks like the transformation from motor coordinates to Cartesian coordinates, the design of the closed loop control and the generation of C-Code which can be compiled and transferred to the Infineon microcontroller. The type of controller the students have to use is a pure pursuit controller. Additionally to the control system a Simulink model of the robot (plant) has to be created that enables the students to test their control system in a software simulation before they transfer it to the robot. These steps show exemplarily the parallelization of development activities according to the V-model (s. chapter 4.1).

Implementation of the Sensor Data Acquisition on the AVR Microcontroller.
All the sensors (infrared, ultrasound or caliper) are connected to the AVR-microcontroller which receives the sensor data and filters it. Subsequently the data is sent to the Infineon microcontroller which uses the sensor data as input for the control system. Therefore this task includes the acquisition of different types of signal on different interfaces of the microcontroller. The infrared sensor for example delivers an analog signal, the calipers a binary signal and the ultrasound sensors transmit their data over an I2C bus. The transmission of the data from the AVR- to the Infineon microcontroller is done via a serial RS-232 interface.

The programming of the AVR-Microcontroller is done in Basic using the BASCOM-AVR IDE (integrated development environment). The students have to learn the required knowledge and basic programming skills like compiling the code and load it on the microcontroller.

Implementation of the Control System on the Infineon Microcontroller.
Since the programming of the Infineon microcontroller has to be done in C and many of the students have little programming experience, the first steps are getting familiar with the software development and the programming language. This means working with the development environment µVision, including the required header files and compiling the C-Code for use on the microcontroller. By introducing two different programming languages and controllers the students should get a better insight into working with microcontrollers.

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When those basic tasks are mastered all functions that are needed to control the robot like PWM-Signal generation for the motor speed regulation, digital input-output operations and RS-232 communication are implemented. The last step is the integration of the control system with the generated C-Code of the Simulink model.

Development of an Electronic Board for the Motor Driver

The development of the motor driver board includes the design of the schematic and layout, etching the board and equipping it with all required electronic components. For the schematic and layout the PCB-software (Printed Circuit Board) EAGLE is used.

When the board is fully completed, the students have to test all the components and check the board. If a malfunction occurs, the students have to find and fix it. This way they become familiar with typical problems that are related to the development of electronic boards and practice the use of standard measurement devices like a circuit analyzer or an oscilloscope.

4.4 Organization of the Student Groups and Project Management

The composition of the student groups is given by the institute. If possible the students in a group are of different age and origin and are specialized in multiple technical disciplines. This is intended to add a more complex social component to the lab, which helps to improve the social and communication skills of the students and creates a more realistic environment.

The project management will be handled by the students. However certain milestones are given in order to ensure the time profile of the course (see fig. 4). The students are supposed to discuss the individual tasks and divide them accordingly among each other. The teams can exchange knowledge, communicate and document their project via a Wiki, which will serve as a team development and management tool.

4.5 Final Presentation and Competition

At the End of the lab, a competition is held between the different groups. It involves the task that the robot has to drive along a curved wall while keeping a constant distance to the wall. The main aspect of the run is the evaluation of the control system and the robot itself. This competition aims to provide additional motivation for the students.

Finally the students have to illustrate their work in a short presentation. Beside the technical results the students have to highlight how they organized the development and which tools they used to support the development process, like the provided Wiki. This information serves as feedback to adjust the lab in the future if necessary. Additionally this feedback about the development process provides valuable data for the institute’s research activities on design methodology [8].

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Week	Simulink	Infineon	AVR	Electronics
1	Introduction			
2	Introduction Simulink	Introduction µVision	Introduction Basic-IDE	Introduction Eagle
4	Transformation	digital I/O	digital I/O	Circuit Diagram
6	Transformation → World Coordinates, C-Code Generation	Timer and PWM	analog I/O	Board Layout
7				Etching
8	Test Drive Robot	C-Code Integration / Test-drive	I2C-Bus	Board
10	Pure Pursuit Control	RS-232	RS-232	Test of the completed board
12	Time Buffer	Control System Integration	Time Buffer	Time Buffer
13	Test of the Robot			
14				
15	Final Presentation / Feedback			

Fig. 4. Timetable of the lab

5. Conclusion and Outlook

This paper presented a new robotic lab for the mechatronic education of engineering students at IPEK-Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT). It showed how the lab is included in the education of the students and presented the technical content and the tasks the students have to solve.

The new mobile robotics lab has been held once in the summer of 2010 so far. The result of an evaluation showed that the lab was very well accepted by the students and kept them highly motivated over the semester. The initial costs to set up the lab amounted to approximately 8000,- € for material and software licenses. Additionally there are running expenses of about 500,- € per semester excluding the personal costs for the two student assistants. These costs have partially been covered by tuition fees.

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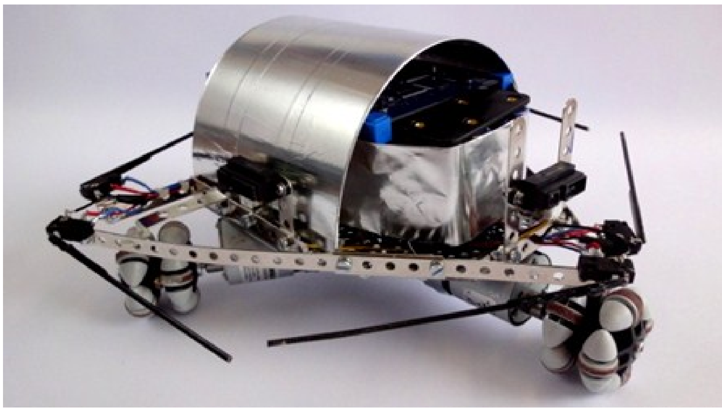

Fig. 5. One of the robots developed in the new lab

As a result of the first run and the evaluation, small adjustments have been done regarding the content and the organization of the lab. E.g. frequently asked questions from the students that occurred during the lab were included in the theoretical lessons at the beginning of the semester. Also the timetable and the deadlines were adapted to balance the workload of the different tasks. Fig. 5 shows one of the developed platforms.

To sum up, the new mobile robotics laboratory has proven to be a valuable contribution to the mechatronic education for mechanical engineering students. In the future this lab will also be included in the upcoming Bachelor and Master program at the KIT.

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