Project course „Design of Mechatronic Systems“ (ICM 2006)

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***Abstract* – The course "Design of Mechatronic Systems" at Technische Universität Ilmenau imparts the systematic procedure of mechatronic design. This paper shows the main features of VDI Guideline 2206, which provides the structured background for students education in mechatronics. Furthermore practical teaching experiences and results from the course are described.**

I INTRODUCTION

Traditional education of technical engineers is based on three main fields: mechanical engineering, electrical engineering and information technology. The development of a new product or the variant design of an existing one needs the interaction of engineers from these three fields. However, the recent development process of new technical products is characterised by a rising integration level of innovations. This leads to highly integrated products with a wide range of new features.

These newly introduced high integration level calls for more than a collaboration of the independent classic engineering sciences. In the 1970's, this interdisciplinary coupling of science fields was named mechatronics. The integration of heterogeneous components to create mechatronic systems requires a development, which reaches above all domains. Thus, the education of young engineers also needs a new concept. In the last years tools and design rules have been developed, which can assist the recent mechatronic design. One example is the VDI Guideline 2206, which describes the methodical and abstract procedure of the development of mechatronic systems. It provides as the framework for student teaching.

II BASIC CONCEPT OF VDI GUIDELINE

For solving a problem by finding the best techniques, its complexity has to be considered holistically. Experiences from research and development in industry and universities are summarised in a structured approach, presented in the VDI Guideline 2206. The aim of this guideline is to support the development of mechatronic products according to a methodical procedure. The VDI Guideline 2206 describes a flexible, multi-plane model, which can be adapted to the particular development. The fundamental procedure for this development is described by the V-Model (Figure 1).

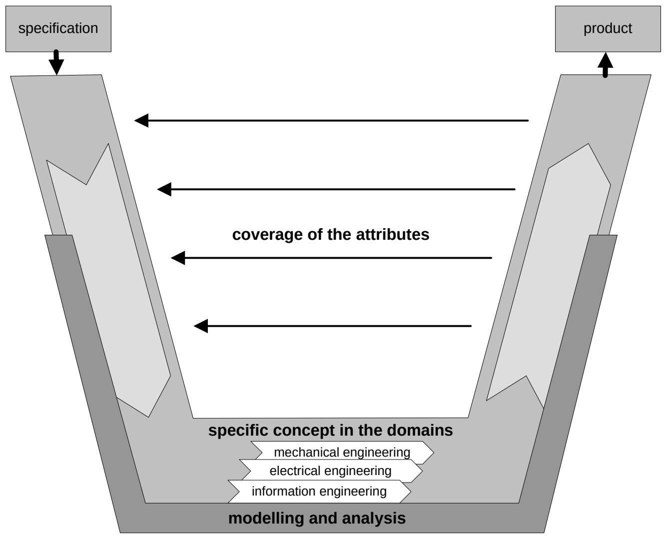

Figure 1
V-Model [1]

The starting point of the development procedure is a specific development request, which contains the specification of the technical and procedural requirements. The detailed definition of restrictions is vital for a successful development of a technical product. The main functions of the future product are split up into smaller sub-functions, presented in the subsequent system design. These sub-functions can be assigned to different active principles. An optimal solution is selected out of the pool of gathered possible solutions. Afterwards, the specific design with consideration of the interaction takes place. In this stage detailed modelling and analysis tools with simulations are used. The succeeding system integration combines the conclusions of the previous parts. The division into sub-functions allows an analysis of the interactions. During all steps has to be kept in the design procedure mind, comparing it with the requirements, in order to achieve the desired features. Often, a complex mechatronic product is not generated in only one cycle, but most likely it will need several convoluted try-outs. The number of cycles will depend on the specific development task (Figure 2).

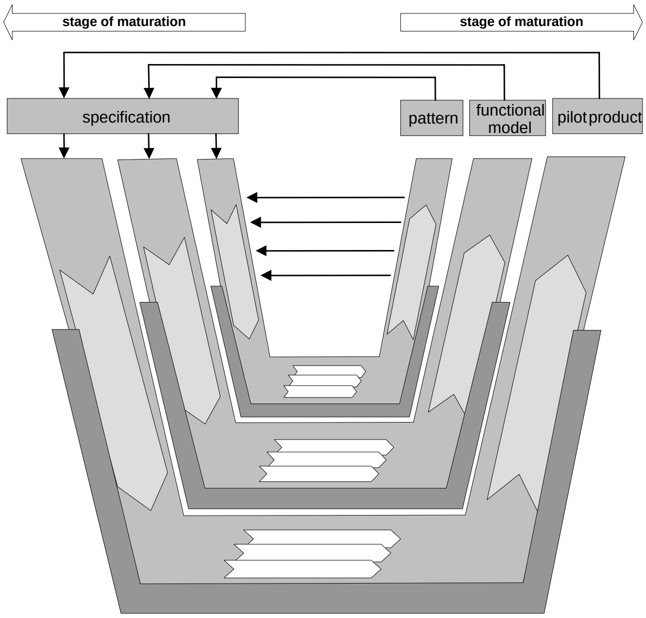

Figure 2
Example for multi-cycle [1]

III BACKGROUND AND AIMS OF THE COURSE

In 1999 the Technische Universität Ilmenau introduced the course of mechatronic studies. The aim of this course is to train the interdisciplinary understanding of mechanical engineering, electrical engineering and information technology.

The basis for an interdisciplinary understanding is a broad education in these three areas of science, finished with a pre-degree after two years. Afterwards the focus lays on a complete overview of mechatronic design including important methods und tools.

A new junior-professorship "Design of Mechatronic Drives" was introduced with the new course of studies. The aim of the professorship is to systematise the procedure of the development of new mechatronic systems. Furthermore it supports the mechatronic design with development and utilisation of novel simulation software. A new project course "Design of Mechatronic Systems" was introduced to impart a structured design process to the students.

IV COURSE CHARACTERISTICS

The course in design of mechatronic systems is a combination of lectures, exercises, laboratory courses and self-dependent project work. The duration of the course is one semester - two hours per week are scheduled for team meetings, exercises and lectures and additional two hours for self-dependent project work. The project is carried out in teams of two or three students, depending on the amount of work to do. The marks are given on the basis of presentations, progress reports and a final report. In a small mechanical and electronic laboratory the students can build up a prototype. Complex parts are manufactured in the mechanical workshop of the university.

All teams have to fulfill the following tasks:

- Problem specification
- Determination of the overall function
- Determination of the functional structure
- Subdivision in part structures
- Search for the best solution for each part structure
- Selection of the best combination
- Manufacturing of the selected components
- Integration of the components
- Function test with the prototype
- Documentation and presentation of the result

The project task is presented to the students in a short verbal description ("purchaser-style"), unlike in usual lecture courses, where the questions are formulated in a way, which already leads to the solutions. The procedure implicates many questions for each topic. In several discussions the questions are answered. In this way, the students will be prepared for the later employment in industry or university.

The course presents the necessity of networking and interactive operating during the mechatronic design process. At the same time, the students are trained necessary soft skills for later professional routines like teamwork and presentation techniques.

By attending the lessons students get familiar with effective ways to solve complex problems. With the use of suitable design tools is it possible to accelerate the design process. This reduces the product costs. Furthermore, students get an overview and insight in modern development software.

A voluntary laboratory course demonstrates the basics of microcontroller programming with "CodeWarrior Development Studio". Within three courses students are taught to implement a program for *Freescale* microprocessor. The topic of the practical course contains simple in-/output operations like a rotation speed feedback control for a DC-motor.

For the students the work starts with a problem description and ends with a prototype. Generally this is a difference to many other courses. Usually students have to make design concepts without even seeing manufactured products.

V PROJECT EXECUTION

A Project assignment

The task for such a project has to accomplish the following demands:

The complexity should be such high, that the structured design method can be applied. On the other hand only simple components may be used because of the restricted resources like time and budget. The project work has to consist of several modules, which allow the teams to work independently.

B Work process

The processing of the project task can be divided in three phases:

1. Conception

This phase is characterised by setting up the concept. In previous lectures students have learned the theory of a structured systematic approach of mechatronic design. Therefore the knowledge only needs to be refreshed in one lecture. Based on the specific task the students can apply their theoretic knowledge and can gain experience in the use of methodical procedures.

The single tasks of the teams and the team sizes were assigned by the lecturer. Each student can expand his knowledge about his favourite topic without neglecting the complete mechatronic design. All students work together on the system design with the help of the systematic procedure. The next step of the specific domain concept is developed in teams. The result of the teamwork is a description of the best solution for each component. Problems are discussed within the whole group to secure the interactions and a clear interface definition.

2. Manufacturing of the components

During the second phase the teams implement the best solution with real components. The students are supported by practical courses, which provide knowledge about the application of modern software, e.g. for microcontroller programming, creating a construction with a 3-D-CAD-model or the layout of a circuit board for a power amplifier.

To realise the project task, the teams need a high level of communication and cooperation. The occurring problems are discussed in weekly meetings including all teams. Continual control of success by means of short presentations ensures continuous working. Simultaneously students train their soft skills. In spite of the fact, that communication, presentation skills and teamwork are necessary for later working life, they are often neglected during studies. Solutions, that seem unsolvable for one person alone, are solved in discussions using the knowledge of the whole group. In this way the course demonstrates the high potential of teamwork.

3. Integration

The last phase is characterised by assembling the manufactured components to an overall system. In most cases, students have to make some small modifications on the components, if the interface definitions were not clear. A function test is the last duty of the course.

VI EXAMPLE

In 2006, the project aim was to build up a robot, which automatically collects table tennis balls. This machine had to move independently and drive around or over small obstacles, while finding and collecting table tennis balls. The robot had to consist of modular components.

A Results from students

After developing the common system model in several meetings, students started the domain-specific draft. This task was solved by special working groups.

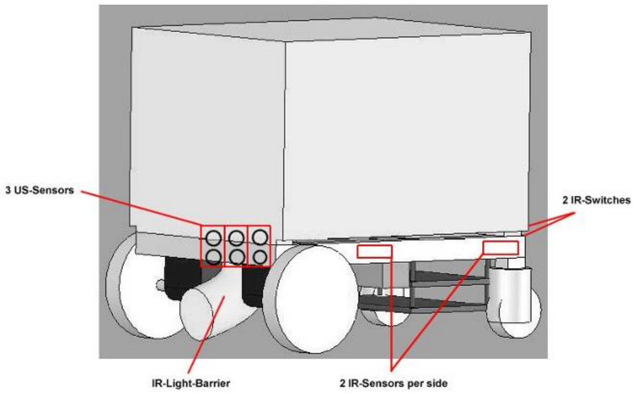

Figure 3
Principle for ball detecting mechanism

The **construction design group** developed the basic mechanical structure with the actuation components. The students planned to steer the robot by using the speed differences of two independently propelled wheels (difference drive). The group dimensioned the drive components and ordered appropriate components from catalogues. The focus laid on a light-weight platform and variable mounting types for the other components.

Two students examined several principles for the **collecting mechanism** and developed a suction principle. Prototypes were investigated to prove the function of the selected principle. The final construction was realised with many off the-shelf components (kitchen box, PC fan), which made the structure simple and cheap. Altogether this group was characterised by a very high creativity.

Two student groups designed electronics for steering the robot and assembled the printed circuit boards (PCB). The **DSP-group** designed and assembled a SMD-PCB with a hybrid processor (MC56F8345). At the beginning it was difficult to choose an appropriate DSP, because the requirements not yet fixed.

The **power-output stage** applies different operating voltages for processor, drive components and sensor technology. The setup of the printed circuit board was worked out independently by the students (preparation of the design documents, assembling and test).

The students of the **sensor group** developed a concept for ball and obstacle detection. They programmed different software functions for the sensor systems.

A **radio group** selected a suitable transmission protocol, assembled the radio connection and programmed an interface to control the robot.

The **programming group** developed the software for controlling the robot. The sensor and radio signals had to be evaluated and drive components had to be controlled.

Furthermore a group for **project management** was established. These students managed the discussions, distributed the information among the groups and summarised the work in an abstract.

B Result of the teamwork

In the last step, during system integration, the single components were united to the overall system, the ball-collecting-robot.

Figure 4
Ball-Collecting-Robot

The results of each group were presented in written and oral form. The presentations were given in English to a European committee for mechatronic education.

VII CONCLUSION

A deeper understanding for interactions can be observed, based on interim reports and discussions with the students during the project phases. A passive attitude at the beginning changed into a lively, active teamwork, while the lecturer took more and more the role of an observer. The students solved problems in the group with further progress of the project.

The construction of a real mechatronic system was a large motivation for the students. Up to this time the students had to work out a lot of concepts for their studies, which had never been tested for feasibility. In discussions with the students as the future engineers, the project gained high acceptance. They learned to apply important draft tools for later project work and gathered experience in using them.

It has to be pointed out, that such kind of course needs very much personnel as well as material resources, compared to usual lectures. Due to the diversity of the main topics, up to four assistants were required to support the students. As far as possible, students were asked to use production technologies being available at university. Some components had to be bought from suppliers (e.g. drive unit, accumulator and microprocessor).

Finally a task is necessary, which can be divided into different sub-functions. The communication between the students is highly essential. Theoretically, systematic design methods can be shown very clearly with such a course. Thus students are able to use these tools later with a high proficiency.

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