Using Low-Cost Hardware to Teach Mechatronics in a Project-Based University Course

KRETSCHMER Jörn[1], FRIEDRICH Jörg[2], SCHIEPP Thomas[3]

[1] *Furtwangen University, Faculty of Mechanical and Medical Engineering, (GERMANY)*

[2] *Furtwangen University, Faculty of Mechanical and Medical Engineering, (GERMANY)*

[3] *Furtwangen University, Faculty of Mechanical and Medical Engineering, (GERMANY)*

Abstract

The syllabus for the mechanical engineering studies at Furtwangen University offers the elective "Mechatronics in practice" for students in semesters 3 to 7. The course goal is to practically apply the previously obtained theoretical knowledge from courses like informatics, CAD and electronics to create a mechatronic system of medium complexity using low-cost hardware. The course is divided into two parts, where the first part consists of a 5-hour lecture introducing the students to Arduino programming with examples on how to control various hardware components and read signals from sensors. Each student group is given a set of motors and sensors that can be used in the introductory lecture and in the project task thereafter. In the second part of the course, the students are asked to define project milestones and allocate the various project tasks to solve the given assignment among the project members. The project progress and the meeting of the self-set milestones is then continuously evaluated by the course examiners during the course progression. The students are free to use the university 3D printers and laser cutter to build the necessary parts for their project. The various group solutions are presented to the other groups in a final event. Course assignments so far included a battle bot, a line-follower robot and a drawing robot. The course experience showed that the various student groups found very diverse solutions to the given tasks with a high quality of execution. The student feedback is collected using a questionnaire. The results of that survey showed a very high satisfaction with the course. Among the various reasons for that was the motivation the students gained through the practical and fun assignments, the possibility to test their solution against the solution of other groups (through e.g. a fight between battle bots or a timed lap for the line-follower robots) and the chance to apply their theoretical knowledge in a practical project. The survey also showed that students invested more time in that course than what is usually required in a course of that scope because they tried to solve the given task as best as possible.

Keywords: Mechatronics education, Robotics, Project-based education, Independent problem solving

1. Introduction

The faculty of mechanical and medical engineering at Furtwangen University offers a study course named "Mechanical and Mechatronics Engineering", which is aimed at providing knowledge in both mechanical engineering through courses such as engineering drawing, design engineering and CAD and mechatronics through courses such as electronics, sensorics and robotics. The study course contains two elective modules in which the students are free to select courses they are interested in. These elective modules are meant to broaden the students' perspective and improve their knowledge in a study area of their interest. Because the majority of mandatory courses are mostly theoretical with written exams rather than semester projects, the students are usually interested in finding electives that provide a more practical learning approach.

A new elective course named "mechatronics in practice" was therefore created to provide for that interest. The course aim was to provide projects that allow the students to practically use their previously obtained theoretical knowledge in informatics, design engineering, CAD and electronics and acquire new skills in order to solve the task. The given tasks should be solved by the groups with as little guidance by the lecturer as possible thus following a problem-based learning approach. Problem-based learning (PBL) is an alternative learning procedure introduced at the McMaster University, Canada in the 1960s. It is frequently applied in education today, because it allows for self-paced learning, a better understanding of the subject at hand, fosters inter-personal skills and teamwork and leads to a higher motivation in solving the task at hand [1, 2].

2. Methods

The course is divided in two parts where the first part consists of a 5-hour lecture that is aimed at providing the students with basic knowledge in microcontroller programming. The students learn how to use Arduino boards to read digital and analogue signals (e.g., buttons or sensors) using appropriate electronic circuits, to control program flow through conditions and loops and to power and control DC motors, servo motors and stepper motors for mechanical movement. The lecture is based on showing various exemplified approaches thus providing the students with sources they can later modify and use in their projects. In addition, each group is given a set of sensors and actuators to allow them to get familiar with the tools they have available to solve the project tasks.

In the second part of the course the students are asked to assemble in groups of four and to define milestones and project responsibilities among the group members.

The groups are asked to meet regularly with the lecturers and present their progress.

The faculty provides the students with various 3D printers and a laser cutting machine along with labs containing soldering irons, electronics and other supplies to build the necessary parts for their projects. The various solutions are presented in a contest at the end of the semester where the groups square off against each other to find which group has solved the task best.

Projects so far included battle bots, line follower robots and drawing robots. With each project the students are given a set of limitations and rules but are unrestricted in their solutions apart from those limitations. The battle bots are limited in weight (500g) and size (20x15cm) and have to be remotely controlled. The drawing robots has to draw a specific set of shapes (rectangle, triangle, oval), while the line follower has to follow a defined path with a set of challenges (interrupted line, narrow curves and start/stop signals) that are indicated by RFID tags. Figure 1 shows the shapes given for the drawing robots and the outlined track for the line follower robot. In the contest, the battle bots compete against each other in 1-on-1 tournaments where a bot wins if the other is disabled or pushed outside the arena. The drawing robots compete for the fastest drawing time and the most exact retracing of the given shapes. The line follower groups also compete for the fastest course completion along with the most exact execution of the given challenges.

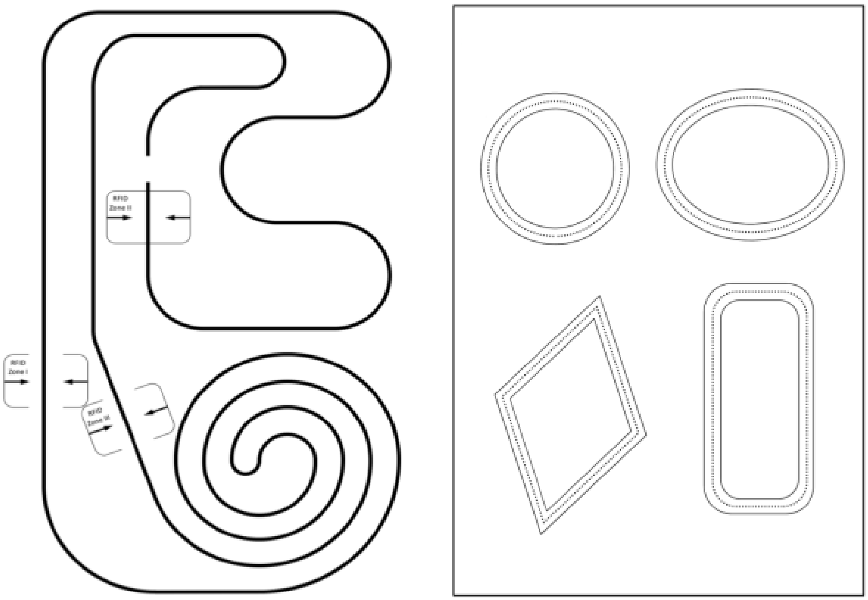

Fig 1. Left: track to be retraced by the line follower robots. RFID zones mark where RFID tags are to be expected. Those RFID tags indicate several challenges: 1 – start/ stop, 2 – interrupted line ahead, 3 – narrow curves ahead. Robots have to react to the tag information independently. Right: Shapes to be drawn by the drawing robots. The drawn lines have to be inside the solid lines.

Student feedback is collected through a questionnaire including yes/no questions, rating questions and free text questions at the end of the semester.

3. Results

3.1 Project results

The course has so far been offered for two semesters with 76 students attending the course. The presented solutions were very diverse and mostly were of high execution quality. One example is the solutions of the groups that chose to build a drawing robot. Here, all groups used two step motors to draw in two dimensions, but with different mechanical designs. One group used timing belts and pulleys to draw the required shapes on a vertical board, one group used a large rotational gear along with a linear actor thus drawing in polar coordinates, another solution attached the step motors to linear gears to draw in x- and y-direction horizontally. Fig. 2 shows the aforementioned solutions.

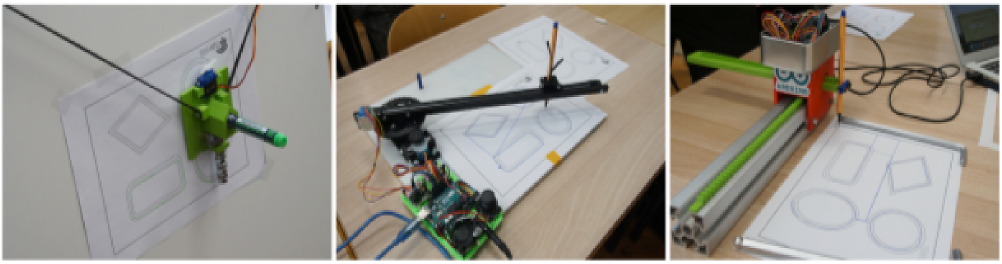

Fig. 2. Different solutions to the drawing robot task. Left: Using timing belts and pulleys to draw on a vertical board. Middle: Using a combination of rotatory and linear movement to draw in polar coordinates. Right: Using two linear gears to draw horizontally.

The battle bot groups also showed a variety of solutions using a mixture of passive (pushing the opponent out of the arena, lowering the chassis to avoid being tipped over) and active (mini saws, water pumps, catapults, spinning wheels, spring loaded pile driver) methods to win. That task especially enabled the students to compare their solutions to other solutions directly, as a poor wiring of the electric components, faulty code or a poor mechanical design lead to an early elimination from the contest.

In addition, it became obvious to the students that simple solutions were more reliable in the contest than highly sophisticated concepts with a higher number of weak points that could lead to failure of the robot.

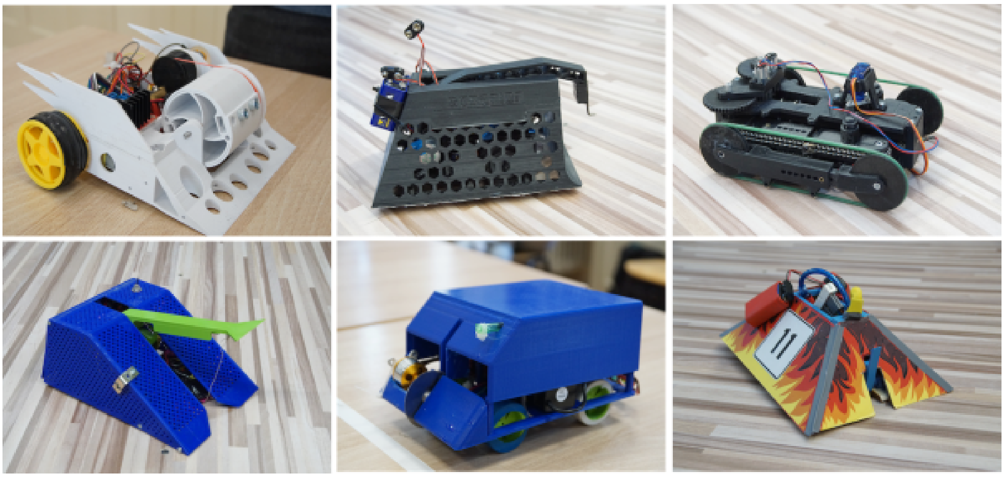

Fig. 3. Various battle bots build by the students. Weapons included spinning wheels (upper left), hooks and a lowerable chassis (upper middle), spring loaded pile driver (upper right), catapults (lower left and lower right) and mini saws and water pumps (lower middle)

Finally, the line follower groups all stated the sensibility of the infrared sensors against scattered light to be the greatest task in their project. Again, different solutions were shown to lead to decent results. Groups used different numbers of sensors to track the outlined course and various approaches to shield the sensors form scattered light such as cardboard shields or mounting the sensors close to the robot chassis in combination with a very low chassis clearance. Additionally, groups used different wheels diameters leading to different line follower speeds and line tracking robustness.

Fig. 4. Various line follower designs. Robots differed in wheel diameter, number of infrared sensors and the placement of the sensors

3.2 Questionnaire results

The questionnaire revealed a very high satisfaction with the course (mean rating of 4.89 on a 1-5 scale). Reasons for the satisfaction with the course were:

- the possibility to put theoretical knowledge gained from the mandatory lectures to practical use
- the minimal limitations thus allowing for highly creative solutions to the given tasks
- the helpful but not stipulating supervision by the lecturers
- the need for autonomous and goal-oriented working by the groups
- the opportunity to compare the individual solutions against solutions by other groups
- the highly motivating projects promoting the students to acquire missing knowledge by themselves

73% of students stated, that they had a high or very high commitment to the task, while 61% stated that they would invest even more time if they would attend the course again. Among the skills the students stated to have improved or acquired through the course were Arduino (83%), teamwork (78%), programming (61%), engineering (56%), rapid prototyping (44%) and CAD (39%).

4. Discussion

The aim of the elective course was to provide students with the possibility to bring their theoretical knowledge to practical use and thereby improve or acquire new skills.

The projects had to be motivating to promote self-acquiring of the necessary skills by the students. The project results showed a high identification of the students with the projects and the questionnaire revealed a high satisfaction with both the given tasks and the course itself. However, there are some drawbacks in the current course design. First, while the single electronic and mechanical components used in the projects are cheap, a high number of components is required to build all robots, thus a semesterly budget for the course has to be appointed by the faculty. Second, at the beginning of the course the students are usually not familiar with 3D printers and laser cutters thus their CAD design might not take into account the design limitations of those production approaches. Therefore, the first attempts at designing the robots and producing the parts are usually trial-and-error leading to a higher work load of both the students and the machines. While the learning by doing approach is part of the problem-based learning, we decided to implement a lecture to teach the design approach in additive manufacturing.

Acknowledgments

This education project was partly funded by the Ministerium für Wissenschaft, Bildung und Kunst Baden-Württemberg (HUMUS, Project PPM – Praxis-Projekt Mechatronik).

REFERENCES

[1] Barrows, H.S. “How to design a problem-based curriculum for the preclinical years”, New York, Springer, 1985.
[2] Barrows, H.S and Tamblyn R.M., “Problem-based learning: An approach to medical education”, New York, Springer, 1980.