Building robots as a tool to motivate students into an engineering education

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***Abstract*—Today, robots have become an integral part of our society: children have robot pets, mobile robots are mowing our lawn and robot arms are assembling cars. Since people are clearly fascinated by these mechanical slaves, we were wondering: why not use robots as a tool to teach more abstract concepts in a practical way. Recently, a new course was added to the first year of the Bachelor's in the engineering program at Ghent University. In this course, first year students have the opportunity to get more hands-on experience through several projects. In this article we focus on one of these, titled 'How to build your own intelligent robot'. This work covers our approach for the practical sessions. Additionally, we elaborate on the low-cost robot platform that was built specially for this course, and which can be used easily by other schools or universities. Two years after the introduction of the robot project, we find that students not only like the sessions, but are very motivated to solve problems which would be otherwise considered too abstract and tedious.**

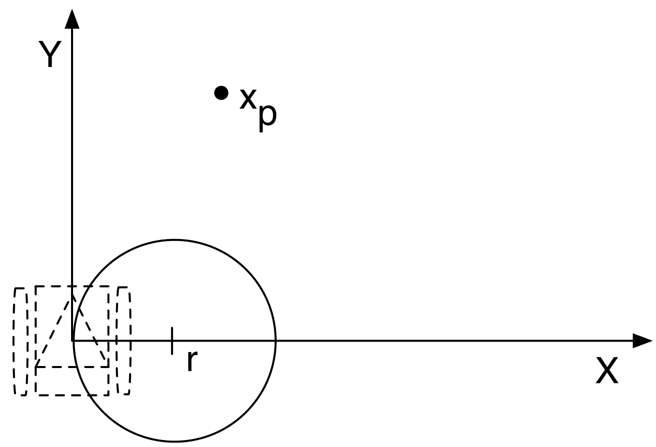

Fig. 1. Graphical depiction of the main geometry problem which the students have to solve during the first milestone. Throughout the course, students look for a solution such that their robot can drive as close as possible to a certain goal x_p. Students start with a two-wheeled mobile robot which is able to drive straight forward or turn with a certain radius r. Next, sensors are added and thus feedback is used to reach the goal. At the end, the morphology of the robot is changed such that the robot can cross obstacles and difficult terrain.

I. Introduction

Nowadays, robots are slowly finding their way from industrial settings to households, clinics and schools. Robotic pets, such as the Sony Aibo [1], are commercially available, robots such as Roomba are cleaning our houses and the first prototypes of social pet robots, such as the huggable robot Probo [2], for robot-assisted therapy are built. Similar to this evolution, robots are finding their way to the classroom [3], [4], [5] although often still hindered by economic constraints and some less successful stories. In [6], authors conclude that robots did not have any positive influence on student learning. However, other studies [7] show that robots can motivate students to actively do things that are not required for the course.

Recently, a new course was added to the first Bachelor's year of the engineering program at Ghent University. After an introduction of nine lectures which cover mainly written and oral presentation techniques, students have the opportunity to get more hands-on experience through several projects. Approximately 400 students have to pick their favorite subject from a list of 19 different projects such as constructing a small but precise catapult, design of a fish ladder and design of an intelligent robot. In what follows we focus on the project entitled 'How to build your own intelligent robot'[1]. This assignment is organized in several sessions during which students try to solve different, relatively small problems, each focusing on a particular problem in mobile robotics.

This work covers our approach for the practical sessions. In the following section we give an description of the course. Next, we elaborate on the low-cost robot platform that was built especially for this course and can be used easily by other schools or universities. After that, we describe the content of the hands-on sessions and the feedback we got from anonymous polls taken by the students.

II. How to build your own robot

The main goal of the course is threefold. First, we show that secondary school math can be applied to a real engineering application. Next we try to give the basics of several practical skills that are useful in robotics. Finally, the students have to improve their communication skills, specifically working in a team and presenting their results in oral and written form. In order to meet our main goal, we organize eight sessions which center around one practical problem: *programming a mobile robot such that it can reach a predetermined end goal in space* illustrated by Figure 1. The students try to solve this problem

[1] Additional material such as pictures and videos can be found on our website: http://reslab.elis.ugent.be/studentcourses

step by step, to break up to problem three milestones were set: *pétanque*, *golf* and *hiking*.

- In the first milestone, *pétanque*, basic concepts of mobile robot kinematics and open loop control are introduced. The students need to solve the geometry of the robot trajectory and perform measurements of the robot speed and movement.
- Next, the second milestone, *golf*, introduces light sensors and closed loop control of the mobile robot. Here, the destination of the robot is indicated by a bright light and a white mark on the floor. Students need to program an algorithm that lets their robot drive towards the light.
- Finally, for the third milestone, *hiking*, students have to rebuild the robot in order to allow its basic morphology to cross obstacles and rough terrain.

To complete a milestone, students have to do calculations and measurements such that they can implement a solution. In order to improve their communication skills they have to defend their solution with an oral presentation and to write down a report.

The milestones are divided over eight hands-on sessions which are organized weekly. At the start of the course, students form five teams of four students which are graded both as a whole and individually. The course counts for six credit units which indicates that an average student spends approximately 180 hours on the course, including classroom lectures. Evaluation is done throughout the semester by means of graded reports, graded oral presentations and evaluation of the given solution and collaboration. At the end of the semester, each group of students has to produce a final written report and a final presentation.

III. Low-cost robot platform

For the course, we searched a robot platform that is cheap, robust, easy to repair and flexible:

- The robot must be cheap in order to make it possible to provide enough robots such that students can work in small groups.
- The robot should be built robustly and should be easy to repair. When a large number of people are working with a device things can break or wear out easily. The robot platform should be robust enough to work under demanding conditions, and if something breaks it should be repairable without too much work.
- The robot hardware should be flexible such that the platform can be adapted to different circumstances and different tasks. It should be possible to add or remove different types of sensors. without taking the robot apart.

We found this combination of properties in a platform we build of Lego™NXT bricks and the Dwengo-board. A photograph of the robot platform can be seen in Figure 2. We designed the robot ourselves with as few pieces as possible. The Dwengo-board is a microcontroller platform with a PIC18F4550 and a wide range of onboard devices which can be used directly to build a robot without the need for designing additional electronics. It comes with a display, motor driver, a USB- and serial port and an expansion connector where sensors can be plugged in easily[2]. The microcontroller can be programmed in C using Microchip MPLAB IDE, the C-compiler is freely available for educational purposes.

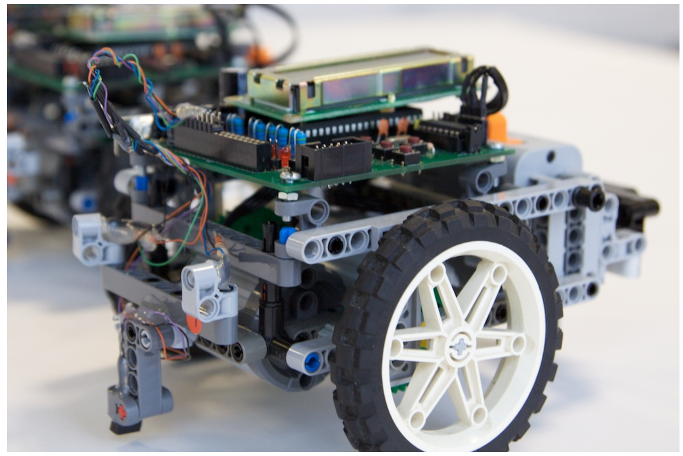

Fig. 2. Robot platform used in the course seen from the front. The construction is build by Lego™NXT bricks. The core of the robot is formed by the Dwengo-board which contains a PIC microcontroller. Through the expansion connector the robot can be extended with multiple sensors. In the visualized setup, two light sensor and one ground sensor was added to the platform.

The power supply of our robot platform is provided by six (rechargeable) AA batteries which can power the robot for the duration of at least one lesson. The total cost of the robot platform is estimated at 120 euro and is determined mainly by the microcontroller platform and the two Lego™NXT motors.

IV. Hands-on sessions

The core of the course are the eight weekly held hands-on sessions. In order to meet the course goals we choose to apply a combination (not necessarily all) of following teaching methods in one session:

- Homework: searching a solution for a problem through homework by investigation of existing literature and using creativity. Often, a session ends with an open question for which they have to seek an answer at home.
- Presentations: usually, the homework included preparation of a presentation in which they formulate their ideas, solutions for the posed problems.
- Brainstorm moments: the student presentations were followed by classical brainstorm sessions during which students try to extract the best elements from each presentation in order to come to a solution.
- Theoretical introduction: during each sessions the main concepts and workflows are introduced by means of a theoretical introduction. We choose to keep these introductions as brief as possible and they never last longer than one hour in order to get maximal attention.

[2]The full specifications of the microcontroller platform can be found on http://www.dwengo.org

Additionally, we interact (questioning, polls, ...) as much as possible to keep them attentive.

- Hands-on work: by applying several methods and doing measurements themselves, students get the most experience in how to bring theory into practice. Therefore, the main bulk of the time slot of the lessons was dedicated to this.
- Competition: at the completion of each milestone, competitions are held such that students are able to compare their results with other groups. They are assured that the result of the competition doesn't directly influence their grades.

As been said before, three milestones are divided over eight hands-on sessions. In order to reach the first milestone, during three hands-on sessions students have to find a solution to program a robot so that their robot can reach a certain goal (x, y) on a flat surface. At this stage, the robot has two wheels and no sensors. Additionally, students have to assume that the robot is limited to drive straight forward over a distance D or taking a turn with certain fixed radius r over an angle θ. Therefore they have to find the angle θ and distance D in function of the goal on (x, y). Some additional problems, such as finding the shortest possible path, have to be solved. Next, students have to measure the properties (speed, possible deviation when driving forward,...) of their robot and estimate the angle and distance so that the robot reaches as close as possible a given point. Since most of the students have no programming experience yet, programming is done through a graphical interface we provided in which they can specify how long the robot has to follow a certain path. The workflow of this milestone is comparable with the game *pétanque* for which a ball has to be thrown so that it lands as close as possible to the object ball. Such as the open loop control of the robot, during the flight, one can not intervene with the ball.

In the second milestone we introduce the concept of feedback. Two light sensors and one ground sensor[3] were added to the robots, while the destination was marked by a light source and a white sign. During four sessions students have to measure the properties of the sensors, program the robot using a state chart, and finally program their robot using the programming language C (using some helpful libraries and starting from a template such that not much knowledge of C is necessary). Again, they have to find the optimal (quickest) way to get their robot to the destination. One can compare this with the game *golf* for which it is possible to correct (by multiple strokes), give feedback, in order to get the ball into the hole.

Finally, the third milestone is devoted to finding a solution to drive a robot, cf. *hiking*, over difficult terrain. Until now, they refined the intelligence and the senses of their robot. However, this doesn't enable it to drive over obstacles or

[3]The ground sensor is distance sensor, but is used to measure the reflectance of the underlying surface. This allows the robot to detect it has reached its end goal, which is marked with a white spot

Fig. 3. A minimalist robot design which illustrates the concept of morphological intelligence: without being programmed to do so, the robot is able to go over obstacles.

irregular surfaces. Therefore each team has to design a new robot that is inherently able to do so by how it is constructed. A good example of this, using a limited amount of pieces, is depicted in Figure 3. The idea is to introduce the concept of morphological computation [8], i.e. using morphology rather than a 'brain' (microprocessor), to solve locomotion problems.

For every milestone at least one presentation and one report has to be completed. After the first presentation and report a lecture is held during which pronounced good and bad things are pointed out. Additionally, for every report we gave some remarks to each group individually.

V. Feedback from the students

Since the first introduction of the course two years ago, we have had one official evaluation (organized by the faculty) and two informal evaluations (organized by the specific lecturers of 'How to build your own intelligent robot'). The overall conclusion is that students highly appreciate our project and our enthusiastic approach. In the official evaluation, students gave the project a score of 87%. Additionally, 90% of the students agreed with the proposition that the course increased their interest for engineering while the other 10% had no strong feelings about this question and thus didn't agree nor disagree.

On top of the official evaluation, we wrote an informal questionnaire, which probes for a more detailed opinion of the course. Again, we learned that students were charmed by the content and our approach. In order to find out whether students found the course useful we posed following three propositions with which they could strongly agree, agree, stand neutral, disagree or strongly disagree:

1) I have the feeling I had to use my creativity during the course
2) I have the feeling I learned from the hands-on sessions

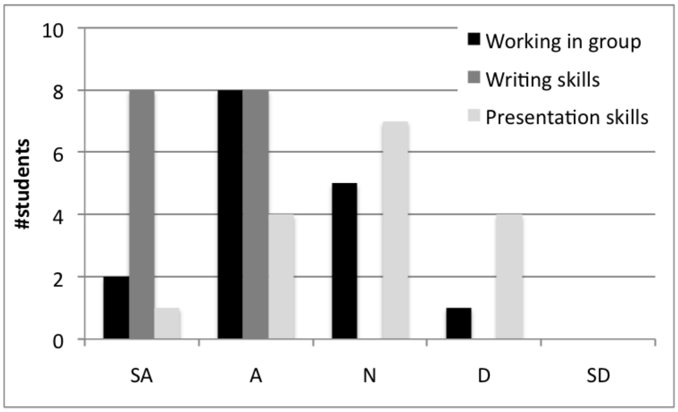

Fig. 5. Results from an evaluation which asks for the success of the course in increasing their working in group skills, writing and presentation skills. Students can strongly agree (SA), agree (A), being neutral (N), disagree (D) or strongly disagree (SD).

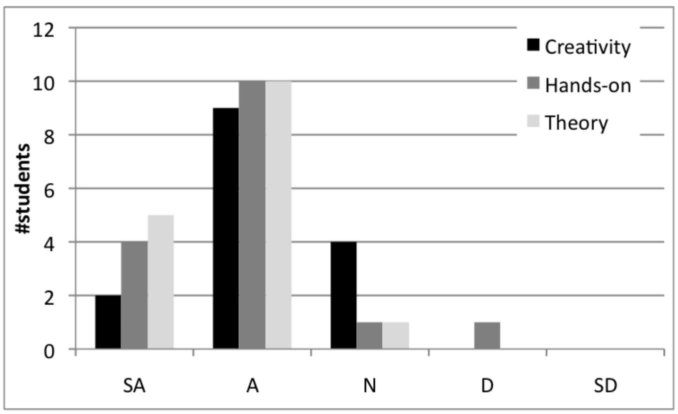

Fig. 4. Results from an evaluation which asks for the level of creativity they had to use, wether they learned from theory or not and wether they learned by doing things themselves. Students can strongly agree (SA), agree (A), being neutral (N), disagree (D) or strongly disagree (SD).

3) I have the feeling I learned from the given theory

On all three questions, students replied positive, as can be concluded from the graph in Figure 4. We belief that a combination of factors form the basis of our success. By implementing a robot platform in our course, students can immediately see the consequences of their thoughts and actions. For the same reason, hands-on sessions where practical engineering skills can be fully expressed form the core of the project. Apart from this, we believe that motivation and enthusiasm of the lecturers also play a role in the positive reception of the course. This enthusiasm is transferred to the students and motivates them to solve the posed problems.

We also wanted to know wether the students found the course helpful in order to improve their communication skills. The following three propositions were posed:

1) I learned how to work efficiently in a team
2) I learned how to write a good report
3) I learned how to give a good presentation

From the results presented in Figure 5 we learn that students are able to work in group, even if the members are not acquainted with each other from start, and that we succeeded in teaching them how to write a good report. However, some students believe that their presentation skills did not increase by our course. We believe we can overcome this problem in the future by giving more detailed and individual feedback of their presentation.

VI. Conclusions

In this work, we gave an overview of the course *how to build your own robot* which is held in the first year of the Bachelor's in the engineering program at Ghent University. In this course, students use high school mathematics to solve problems in the domain of mobile robotics. Additionally, student communication skills are increased by working in group, writing reports and giving presentations for a group. From student polls, we learned that students not only gain useful new skills but are also motivated to solve problems in the domain of engineering which could be otherwise found abstract and tedious.

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