ABSTRACT

This paper describes the pre-training approach using research projects to get the in-coming mechanical engineering undergraduate student jump started for their four years of college career. We used a robotics research project to go through the full engineering design lifecycle, including (a) brainstorming, (b) feasibility studies, (c) building simple models for evaluation, and (d) engineering/construction. With the help of the mentors, the approach has effectively involved the students to identify potential problems and solve them effectively during the execution of the projects. The resulting constructed robotic delivery truck is a mathematically interesting problem that will be solved as a research problem.

1 Introduction

In this paper, we present our experience in a robotic project with two Fall 2009 semester in-coming undergraduate mechanical engineering students over the summer 2009 at The Laboratory for Autonomous Robotics and Systems (LARS) at The University of Texas at Dallas. The overall goal of the ten-week project was defined to design, program and construct service robots for delivery purposes using different mobile robots. The two students involved in the project were selected and sponsored by the Anson L. Clark Summer Research Program\(^1\) [1]. At the conclusion of the program, the students were expected to summarize their work in the form of presentation at a university sponsored research conference.

Robotics is a very multidisciplinary field that can provide a wide range of pre-training for such in-coming mechanical engineering students. In fact, as noted in “National Robotics Technology Roadmap” [2], “owing to the inexorable aging of our population, the emergence of such a next generation ‘robotech’ industry will eventually affect the lives of every American and have enormous economic, social, and political impact on the future of the nation.” This shows that robotics technology is going to be one of the major transformative technology in the next decade, which is like the Internet technology that changed the daily life of every individual within the past decade. To this end, it is very important to train the next generation so that they are prepared for the next generation robotics applications in their daily life.

Robotics is one of the best field to jump start a student for engineering skills since it integrates a lot of the emerging fields in engineering, especially mechanical, electrical, control and computer engineering. These multidisciplinary subjects are inspiring since most of the time it can result in very exciting working re-

\(^1\)The program is a scholarship program offered by the Office of Undergraduate Education of UT Dallas. The program selected some of the best applicants based on their academic achievements. The program not only supports the robotic research presented in this paper, but also some other engineering and science programs. See the cited website for more information.
results without too much complex equipment, yet its challenge is complex enough to allow the students to learn very relevant engineering process. The challenge then comes from which area of robotics that the student should first learn. Lego Mindstorm is an excellent platform that free out the most of these challenges for the first step in learning robotics. Both mechanical and programming approaches adopted are in the form of “building blocks” that hide a lot of low level constructions from the beginners. This is important since it can keep them motivated and eager to understand further. They potentially only need to think about the logical flow to perform the functionalities that they desire based on the “resources” available. In terms of example case studies, reported in [3], Lego has been used to teach basics of robotics in high school. Even in the undergraduate career, Lego can be used to teach various control projects [4], where the instructors can focus on the control and/or programming parts of robotics in their curriculum instead of starting from scratch.

About a decade ago, iRobot commercialized robotic vacuum cleaners called Roomba at a competitive price. The robotics education community quickly realizes its value for educational platform, and many efforts have been put. For instance, a Robotics Primer Workbook [5] was published due to this effort. Due to its very low resolution sensing capability, some research has also been done using this platform to improve its localization capability [6]. iRobot later commercialized the educational robotics platform based on Roomba and called it iRobot Create, which provides an even simpler control protocol. Mataric et. al. [7] later even argue more specifically how cost effective this approach in learning robotics. Esposito and Barton [8] created a MATLAB Toolbox for the low-level interaction with the robot. This allows even simpler programming in MATLAB for robot hardware interface, and many interesting projects were created with the toolbox. Of course, the complexity of the problem can be added if gumstix based processor is introduced, which is for the learner who wants to achieve more flexible results, for instance, the real-time application [9].

It has been motivated by Matarić [10] that robotics education should be for all ages. Many efforts have been put to encourage students start learning robotics at their very young age. This can be particularly noted by the many different robotics competitions that support high school engineering outreach education, including Boosting Engineering Science and Technology (BEST) by Best Robotics, Inc. [11], VEX Robotics [12], and US For Inspiration and Recognition of Science and Technology (FIRST) [13]. Furthermore, recently, a robotics research group in University of Pennsylvania (UPenn) even held a very intensive robotics program for high school students [14], and many surprising results were presented. There were also many other computer science related educational effort, such as Python Robotics (Pyro) [15] that emphasizes specifically at the programming level. Finally, virtual prototyping skill is also very important in robotics design, and the first author also involved in some of these projects that both emphasize the use of web technology [16].

This paper presents the detailed process involved in this project by the two in-coming mechanical engineering students. We believe that the experience is worth documented as an example and should be expanded to other institutions. The rest of the paper is organized as follows: Section 2 first motivates the approach that was implemented in the program. Section 3 details the project execution, including the hardware prototype and Lego programming. Finally, Section 4 concludes the paper with comments from the participants and suggested future work.

2 Motivation and Approach

When starting their new positions, most engineers start with the approach where “the supervisor tells me what to do, and I follow”. While today’s engineering problems are getting more and more challenging, supervisors are less likely to be able to outline the detailed step-by-step guides of the entire engineering process for a team of engineers to follow. Most of the time, the supervisor outlines the high-level expectation to the engineers, and the engineers are expected to work independently to come out with solutions to the problems with the available resources. Engineers are then expected to report to the supervisors with their progress, so that the supervisor is able to either making sure the engineers are on the right track, or helping them in solving problems that are beyond their ability and experience.

Hence, in this project, we implement such approach to the in-coming students. We must get their “assignment-based” mind-set out of their mind, and expect them to come out with the processes needed to solve the encountered problem. They also have to realize that the available resources are always limited, and there is always a need to search for an optimal solution. Finally, they also have to realize that when working on a project, there is no well-organized and “correct” path to solve a particular problem. They have to think carefully on what the possible alternative solutions are and what the consequences of them. The point is we have to let them realize the problems when making mistakes, and, potentially, having the mentors to help them to solve in the innovative manner. In this way, they will understand the problem further, and potentially not making the same mistake again.

Furthermore, as suggested in [14], the top-down approach can be favorable since students tend to give up when going through the difficult preliminary mathematics, science and engineering courses. Our situation is one of such perfect example,
where the students had no prior knowledge in engineering analysis and programming. Also, as suggested in [17], motivated by practical engineering projects can often inspire the students to continue to work in the field, and able to build the relationship between what they learn and the project. Hence, in this project, we assigned the students with a very interesting projects of the building "a device" that can have the robots to work together to deliver large object. In addition, while the programming aspect of robotics is important, there has been also growing need in equipping students with mechanical skills to be integrated. Thus, in this project, we also emphasize the CAD-based virtual prototyping [16] and hands-on physical prototyping experience.

2.1 Organization and Mentoring
As mentioned previously, this program is a ten-week research program. The students worked in the Laboratory for Autonomous Robotics and Systems Monday to Friday 9:00 am to 4:00 pm daily over the summer. Within the Clark program, the students also required to participate in other activities organized by the program management, such as general leadership and research training, which is not the scope of this paper.

The selected students had very strong background in science and technology, and also demonstrated fast learning capability. Hence, we spent considerably less time in instructing them, but rather suggesting them high level solutions to problems and issues. The mentors met the students weekly, and we often had open discussions between the mentors and the students, more than direct instruction from the mentors to the students. The students were required to report to the mentors as soon as they reach the milestone. Often, they were required to take videos of their accomplishments, and posted them on YouTube.

3 Project Execution

The lab is equipped with a number of iRobot Creates, shown in Fig. 1. As mentioned in Section 1, the robot is a programmable differentially driven wheeled mobile robots. Our goal is to have multiple of these robots to work together to transport a large object - one of the examples is shown in Fig. 2 [18]. In order to brain-storm for fresh idea, we did not show any of such “structured” example to the students. We understand that the number of required robots depends on the object size, and we want to build a mechanical platform that can “scale” the attachments of these robots so that they can carry the object in a coordinated manner.

We executed the design and implementation processes in stages. We broke down the entire project into two major sub-problems. First, in order to design the system more cost effectively, we had the students first constructed their designs in the CAD software, such as Solid Works. Since we have scratch wooden parts in the lab, they could used them to construct what have been constructed in the CAD models. Second, after the mechanical prototype was constructed, we needed to build intelligence to coordinate the robots (or to perform the delivery function). Since the students did not have sufficient programming background, we took an alternative approach to let them try to programming robots. We used Lego Mindstorm to let them to construct different possible configuration of the delivery robots, and have them program with interesting tasks. While the intention was to integrate the first and second part of this project together, due to both time limitation and their ability, we declared that the project was accomplished. Indeed, the project had been very well executed by just two students in just 10 weeks.

3.1 Project 1: Cooperating iRobot Creates Carrying a Common Wheeled Trailer

We first held a number of brain-storming sessions as to what can be done in order to achieve the goal of the project. Specifically, we “formulated” the problem as follows:

\[ \text{Given the iRobot Creates, how can we arrange them in order to work together using mechanical structure more effectively?} \]
Various ideas were conceived, including just placing a board above the robots and connected them with joints; equipped a platform with caster wheels underneath and hinged them to the robots; etc. Finally, they came out with the smart idea of “oxen pulling a trailer”, where the robots act like the oxen, and they just needed to construct wheeled trailer to hook on the robots.

As described previously, to save cost, they started to try out different mechanism ideas for the delivery robotic truck in the CAD model. The CAD model first created to analyze the feasibility of the system prior the hardware construction. Specifically, they used the assembly mode in Solid Works to visualize the moving parts so that they could “analyze” the feasibility of their ideas. A specially designed link that allows modularly attaching either one or two iRobot Creates together with the trailer was constructed. They also started to look for bicycle wheels that form the wheels for the trailer. The finalized idea was constructed elegantly in Solid Works, as shown in Fig. 3(a), especially the detailed complicated spoked wheel model shown in Fig. 3(b). Without prior Solid Works or CAD experience, and with this accomplishment, this shows that how much can high school students can achieve today in using CAD software.

They identified all the parts needed to be constructed, and exported the corresponding CAD model to engineering drawings with proper dimensions - see Fig. 4 for two examples. Since one of the students has prior machine shop skill, we allowed them to use some of the basic mechanical tools in the lab to start constructing the physical prototype. The physical prototype was created out of wooden parts - see Fig. 4(b) and Fig. 4(d). Fig. 5 shows the successful creation of the mechanical prototype. The trailer allows one robot (Fig. 5(a)) or two robots (Fig. 5(b)) modular attachment to the constructed trailer. Of course the immediate question would be how to attachment more than two robots, which will be addressed in the future.

In fact, they created a mechanical system with a mathematically interesting nonholonomic problem of robots with trailer [19, 20]. The coordination between the two robotic modules to create the coordinated trailer motion is not straight-forward, which is currently pursued as a research problem. Therefore, this can also motivate them to do well in physics and mechanics so that they can solve such problems in the future.

Finally, the video of the robot in motion can be found on: http://www.youtube.com/watch?v=NL24Kmc3NOI. Overall, Project 1 took approximately 4 weeks to accomplish.

### 3.2 Project 2: Lego Mindstorm Automatic Delivery Robot

Since the students had not had sufficient programming and mechanics background to program the iRobot Creates such that they can coordinate properly for the object delivery operation, we took an alternative approach to let them learn programming. As mentioned above, Lego Mindstorm is a great tool to fulfill this since it effectively free up a lot of the low-level implementation details, while sufficiently complex algorithm can be created. We scaled down the problem, where the robot is required to deliver mails. We stated three major goals to fulfill this project:

1. The robot is able to pick-up and drop-off the mail at specific locations based on user input
2. The robot should be able to deliver the mail autonomously
3. The robot should have enough clearance to perform the required maneuver

Three major aspects were examined and studied in this project, including mechanical design, programming and testing.
3.2.1 Mechanical Design The students first designed various mechanisms for the trailer to effectively pick up, delivery and drop off the mail. Two major alternatives were built, which are illustrated in Fig. 6(b) and Fig. 6(c). In the first design in Fig. 6(b), they quickly realized that using the motor to lift the entire cantilever-trailer can be difficult. Hence, they created a more structurally rigid trailer to hold a more robust mechanism to pick-up and drop-off the mail. The disadvantage was more parts were required.

3.2.2 Programming In terms of algorithm implementation and deployment, note that three Lego Brick Controllers were used. Two Bricks were installed on the truck head, as shown in Fig. 6(a), to perform: (a) the robot motion to follow a straight line, and (b) to determine the position to drop of the mail. Another Brick was installed on the trailer, just to control the actuator for the mail drop-off mechanism. All these three Bricks were communicated through Bluetooth for data exchange. Four IR sensors (light sensors) were used to localize the robot: (a) two light sensors at the side to make sure the robot moves in the straight line, (b) one light sensor as counter, and (c) one light sensor to make sure the robot to be able to turn 90 deg.

During the process of programming the Brick, two major issues arose:

LabVIEW graphical vs. script programming As shown in Fig. 8, while LabVIEW-based graphical programming can be attractive, some very intuitive programming can probably be easier done in script-based programming. This was especially noticeable for the if-then-else loop. In addition, they also realized that they could not nest two if-then loop when implementing mechatronics devices (i.e. instead of nesting “if-then”’s for both sensor and actuator commands, they had to separate them).

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The students ran out of memory to store the program to realize their ambitious goals. Fortunately, the controller comes with intuitive Bluetooth interface that allow them to pass data from one Brick to another easily. Hence, in this case, as mentioned earlier, they distributed their programming tasks into three Bricks.

### 3.2.3 Testing

They also learned how to structure their staged experiment test, where they started from the simpler tests, and move to the more complicated tests when they gained confidence from the preliminary tests. In this case, they were using the IR sensor to detect and count the white and black surface on the floor to localize the robot. They first wanted to understand the performance of the sensor and their algorithm in such implementation. They first created a small test site outside the lab shown in Fig. 9(a) to perform the simple test. They again quickly realized the sensitivity of the sensor to the white specks on the tiles, and they could only use electrical tapes to block these specks. The video on http://www.youtube.com/watch?v=PS_EYDpfhIU is the preliminary test of the Lego Mindstorm delivery truck. It uses the light sensor to detect the white and black contrast so that it can maintain the straight line motion. At the later stage, such method is also used to determine the number of room traveled by the truck.

The students finally created an intelligent robotic system that can delivery mail automatically to the door of the recipients along a corridor, shown in Fig. 9(b). The user simply input the room number to the Brick, and the robot will deliver and release the mail completely autonomously. The video on http://www.youtube.com/watch?v=06yekd6rYIo shows the Lego Mindstorm delivery truck to deliver mail from one room to another specified room. It uses the infrared sensor to detect the white strips on the floor, and, hence, the number of rooms traveled. Overall, the project took about 4 weeks to
accomplish. The remaining time was for the documentation and presentation preparation.

The project concluded with the Clark Research Program Conference, where the participants were required to present their work in the PowerPoint form. Hence, not only they successfully accomplished the robotic project, the students also learned how to create presentation slides to effectively communicate to the audience. Throughout the process, the students were encouraged to take videos to show their progress. These videos effectively formed very good way to document their design process, as well as to present their work.

4 Conclusion

In conclusion, the project was accomplished successfully. We used a robotics research project to go through the entire engineering design lifecycle, including (a) brainstorming, (b) feasibility studies, (c) building simple models for evaluation, and (d) engineering/ construction. With the help of mentors, the approach has effectively involved the students to identify potential problems and solve them effectively during the execution of the projects. Overall, the students expressed that the learning process was very effective. They had more confident in starting up their 4-year mechanical engineering career. They also expressed their interest in coming back to work in the lab. In fact, they are now very active members of student chapters of ASME and IEEE Robotics and Automation Society at UT Dallas.

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REFERENCES


