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Using LEGO MINDSTORMS in a Control Systems Lab to impact next generation engineers (Works in Progress)

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Abstract

Producing interest in control systems can be challenging due to the abstract nature and increased mathematics needed to understand the topic. This paper explores three applications of using LEGO MINDSTORMS kits to further education in controls and system undergraduate research, K-12 outreach, and in-class labs. Encouraging undergraduate students to design an outreach activity facilitated a research experience for the undergraduate students. This outreach activity was incorporated into a three-hour workshop, which allowed high school students to explore the field of controls and systems by programming the NXT brick. The kits were also the basis of a series of labs for an undergraduate systems course. By providing students of multiple levels hands-on experience, it is our hope to inspire future engineering students, and further develop the knowledge of future engineers.

1. Introduction

Teaching students about control systems is challenging, specifically due to the increased mathematics necessary to fully understand the topic. The LEGO MINDSTORMS kits, due to their low-cost, simplicity, and great flexibility, have been widely used in K-12 and colleges for hands on teaching of robotics and controls[1,2]. The Penn State Erie, the Behrend College (PSB) is also an affiliate partner with First LEGO League and offers a variety of resources for those teams. This partnership, along with a strong K-12 outreach presence in the area, made the LEGO MINDSTORMS option a natural choice for controls education. Thanks to the IEEE CSS outreach grant, we were able to incorporate LEGO MINDSTORMS NXT to develop control lab activities that can be used for K-12 outreach and undergraduate education to foster an interest in Mechanical Engineering, as well as advanced level activities for the purpose of educating undergraduate students in controls and systems.

System dynamics and control is a field with applications in a wide variety of topics including robotics, biology, ecology, and psychology[3]. The mathematics required to fully explore the topic can be challenging for students in both K-12 and the college level[4,5]. Providing students with hands on experience with the LEGO MINDSTORMS kits can be a informative and positive experience[6,7]. By using these kits for multiple purposes, interest can be fostered in the field for both current and future engineering students.

The hand-on experience developed included an outreach workshop for K-12 programs. One example was an immersive 3-hour control systems workshop for use in the Minority College Experience/Women in Science and Engineering (MCE/WISE) summer program, which was conducted in July, 2014 with over 30 students. The MCE/WISE programs are free programs, offered by PSU Erie, designed for minority or female students from the Erie area in the summer before their senior year in high school. This program offers students the opportunity to explore their options in higher education and examine

possible career paths. Along with STEM related field trips, in-depth workshops, and experiences, the students take a free 6-week college course.

In our workshop, the high school students not only had a chance to build an automated wheeled car and a grasping robotic arm, but also observed that changing controller parameters in MATLAB/Simulink resulted in a change in the performance of their robots. The outreach activity instruction was developed by two junior mechanical engineering students supported by the PSB Undergraduate research fund, under the supervision of one faculty member. This outreach lab can be incorporated into any immersive engineering outreach activity for middle school or high school students.

Additionally, three lab activities for junior and senior mechanical engineering students were created. The Department of Mechanical Engineering at PSB offers a course, System Dynamics, which covers theory of modeling, analysis, and control of dynamic systems. Simulation tools (MATLAB/Simulink) were used extensively throughout the course. Students are introduced to designing basic controllers including Proportional Derivative (PD) controllers. An end of semester position tracking project, using a Quanser DC (direct current) controller unit, was the only hands-on experience provided. Due to the limited availability of these units, students' experience was limited to fifteen minutes of experiment verification of their PD controllers. The newly designed Lego labs were introduced in Fall 2014, and now impacts more than 100 students annually. The labs include (1) a time response of first order system and transfer function identification and verification, (2) a time response of second order system, and (3) a PD controller design for a tracking problem. These lab activities in the System Dynamics course will evolve into a one- credit lab course, Dynamics and Control, to be incorporated into the curriculum of the Mechanical Engineering program. This effort of creating a specialized dynamics and control track is aimed to attract mechanical engineering students to pursue future careers in the field of dynamics and controls.

2. Methodology

The LEGO MINDSTORMS kit was used for three areas of education; undergraduate student research, K-12 engineering outreach, an in-class hands-on experience for undergraduate students focusing in the field of system dynamics. The student researchers assisted in the creation of the outreach activity, and helped write the assembly guides for both the outreach activity as well as the in-class labs. The outreach activity allowed high school students to assemble two robots, a car and a claw, and program each robot using the internal NXT brick software, as well as using MATLAB/Simulink. The in-class labs were created for system dynamics students to have hands-on experience to support the theoretical material presented in their course.

Figure 1: The robot car built during the K-12 outreach activity

Undergraduate Student Research
Two junior undergraduate mechanical engineering students were supported by Pennsylvania State University, Behrend College Undergraduate student research grant to develop an outreach activity for high school aged students using the built in programing in a LEGO MINDSTORMS NXT Brick. The student researchers also created the build instructions for high school students to be able to create the LEGO assembly needed for the two robots (the robot car and the robot arm) created in the outreach activity. Their build instructions for the robot arm were used in the undergraduate systems lab course.

Engineering K-12 Outreach
The K-12 hands-on activity was designed to both have the students understand the logic of using a program to control a robot, as well as the connection between system parameters and system response. The outreach workshop consisted of two main activities: (1) building and programing a LEGO car that can drive straight into a 2ft by 3 ft area, and retreat before hitting a wall, and (2) building a claw that could grasp and release an object. Changing system parameters in MATLAB could affect the amount of time to finish the second task.

For the first activity, designed by the undergraduate researchers, the students were responsible for selecting an appropriate sensor such that the car would be able to detect the wall without touching it, and programming the NXT brick directly to allow the car to

perform the activities. The students were provided with a set of instructions on how to build the car, and how to attach any of the potential sensors. The potential sensors included with the LEGO MINDSTORMS kit included an ultrasonic proximity sensor, a light sensor, a sound sensor, and a touch sensor. After selecting a sensor, students had to program the NXT brick to move forward until the sensor detected otherwise, and move backwards upon sensing proximity to the wall.

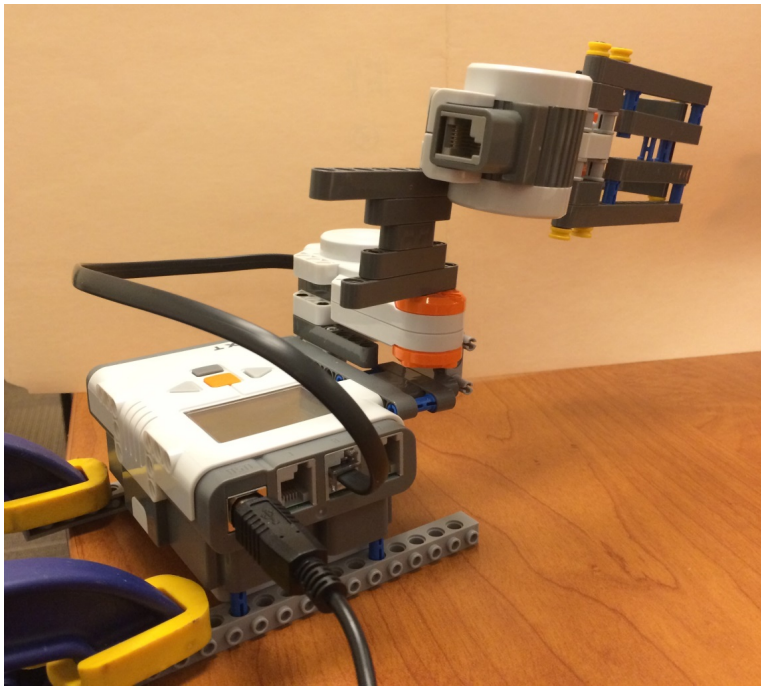

Figure 2: The robot claw attached to the LEGO MINDSTORMS NXT brick.

The second activity, developed by faculty members, allowed the students to see the effect of controller design. The students were responsible for building a claw, as seen in Figure 2, that could grasp a dumbbell created from LEGO tires and a connection rod, rotate the claw 90°, and then release the dumbbell. In this case, the software was coded beforehand, in MATLAB/Simulink. The students had control over the derivative and proportional controllers, and could change the values of the parameters. Their objective was to have the robotic claw grasp, rotate 90°, and release the dumbbell in the shortest time possible. This activity demonstrated a more quantitative study of robotics and control. After both activities the students were asked to complete a survey indicating if they found the workshop interesting, thought provoking, and if they would recommend the workshop to others.

In-class Systems Lab

In order to provide a hands-on experience for undergraduate students a set of lab activity using MATLAB/Simulink programs were created. Those programs can be downloaded to the microcontroller of LEGO NXT brick through USB cable, and the sensor data can be transferred through Bluetooth simultaneously to MATLAB/Simulink environment for

quantitative study. The three in class labs focused on three major system dynamics topics: (1) display understanding of time response by identifying the time constant τ for a first order system, (2) identify overshoot, peak time, and rise time of a second order system, and (3) design a PD controller for a tracking system.

The first order system used as the basis for all three labs was the same robot claw used in the K-12 outreach activity. In the first lab students had to plot the response of angular velocity of the claw to a step function. Using the actual results of the claw angular velocity to the step function, the students had to predict the time constant τ, as well as the transfer function of the first order plant. They could then have a theoretical result plotted with the actual angular velocity to verify their transfer function.

In the second lab, speed position of the claw was the tracked variable, and a proportional controller with a fixed value was set. The resulting second order system was under-damped, which meant that a step-function would result in an overshoot. The students had to use their transfer function that they identified in the first lab to derive the second order system step function response.

During the third lab, students had control over the values of a PD controller, and had to use control theory to determine values for the controller to meet the required restraints on settling time and overshoot percentage. This lab was similar to the K-12 outreach activity, however students were expected to have used control theory to identify usable values for the PD controller.

3. Results

The purpose of this study was to use LEGO MINDSTORMS system to enhance engineering education K-12 outreach, undergraduate student research, and provide hands-on experience to students taking system dynamics.

The two junior students who helped manage the outreach activity, by creating supporting documents and designing the robot car challenge, had a very positive experience. The assembly instructions for both the outreach and the in-class labs were developed by the student researchers, and were clear to follow. The students reported that the balance of research during the semester allowed them to develop time management skills. They were able to identify the ties between their classes and the outreach activities. By contributing to K-12 activities, they could see their effect on the next generation of engineers. The outreach instructions are in Appendix A.

The K-12 outreach activity was held for those involved in a summer program for high school students, MIE/WISE. A total of 34 high school aged students participated in the three-hour outreach activity, in groups of 4-5 students. All the groups were able to finish at least the first activity, more than half of the groups finished the second activity. None of the group has issues with hardware or software problems. The response of the students to the after workshop survey is listed in Table 1. The majority of the students had a positive experience, and saw the workshop as beneficial.

Table 1: Response from participants of the K-12 outreach activity

	Agree Strongly		Neutral		Disagree Strongly
Ranking	**1**	**2**	**3**	**4**	**5**
The workshop was interesting	21	5	6	0	2
The workshop made me think	23	5	5	1	0
I will recommend this workshop to others	17	8	7	0	2

The first semester of in-class lab activities were unfortunately hindered due to license and memory complications. Those activities were done in a different computer lab from the outreach activities. The computers had difficulty running the MATLAB software on the NXT bricks, which resulted in the computer crashing. As a result, only a few students were able to complete the activities each lab. This understandably resulted in frustration on the students' class feedback. By deploying the software to the NXT bricks before running the simulation, these crashes can be avoided. These labs will be re-run in the Spring 2015 semester, and this issue will be resolved by then.

4. Discussion and Conclusion

Understanding systems and control theory can be difficult due to the high level mathematics required. The LEGO MINDSTORMS activities were designed to cover controls at both a K-12 as well as a junior engineering course level. The Engineering K-12 Outreach Center offers more than 50 events every year to around 5,500 plus students, teachers and parents, mostly from K-8 grades. Adding activities based on control systems and robotics to the repertoire would help to increase the visibility of many of the engineering programs, particularly increasing the exposure to high schools students.

A trial run of the in-class lab was conducted in the Fall 2014 semester. Due to the technical difficulties, the labs were stressful to students who were unable to finish the lab in the given time period. However we expect to finish a complete study on the effect of these labs in the Spring 2015 semester courses.

The purpose of the LEGO MINDSTORMS experience was to use the kits to provide educational experiences to K-12 students, undergraduate students, and students involved in undergraduate research. The undergraduate research and the outreach activity proved to be very positive. With time we might be able to combine the lab activities and have undergraduate students introduce K-12 students to the joy of engineering and controls.

Acknowledge:

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5. Bibliography

1. Kim, Y., Control Systems Lab Using a LEGO MINDSTORMS NXT Motor System. IEEE Transactions on Education, 54(3), 452-461, 2011.
2. Cruz Martín, J.A. Fernández Madrigal, USING LEGO MINDSTORMS NXT ROBOTS FOR CONTROL SYSTEMS COURSES IN UNDERGRADUATE ENGINEERING PROGRAMS, 2nd International Conference of Education, Research and Innovation, 5887-5898, 16-18 November, 2009, Madrid, Spain.
3. Strogatz, Steven H. Nonlinear dynamics and chaos: with applications to physics, biology, chemistry, and engineering. Westview press, 2014.
4. Skaza, H., Crippen, K. J. and Carroll, K. R. (2013), Teachers' barriers to introducing system dynamics in K-12 STEM curriculum. Syst. Dyn. Rev., 29: 157–169. doi: 10.1002/sdr.1500
5. Baillie, C., & Fitzgerald, G. (2000). Motivation and attrition in engineering students. European Journal Of Engineering Education, 25(2), 145-155. doi:10.1080/030437900308544
6. Sergey A. Filippov, Alexander L. Fradkov, Boris Andrievsky, Teaching of robotics and control jointly in the University and in the high school based on LEGO MINDSTORMS NXT, 18th IFAC World Congress, Milano (Italy), August 28 - September 2, 2011.
7. Alimisis D., Robotics in Education & Education in Robotics: Shifting Focus from Technology to Pedagogy, in David Obdrzálek (ed.) Proceedings of the 3rd International Conference on Robotics in Education, September 13 – 15, 2012, Charles University in Prague, Faculty of Mathematics and Physics, Prague, Czech Republic, pp. 7-14.

Appendix A: K-12 Outreach instructions

Outreach Activity: Robotics and Control using LEGO MINDSTORMS NXT

Activity 1:
Objective: Build and program a robot (wheeled car) to drive into a space and exit as quickly as possible without touching the wall.

1. Build the basic configuration. (see attached instructions). Connect the motors of the wheels through a cable to the motor ports (A, B, or C)
2. Decide which sensor(s) your robot will need to complete the task. A description of each sensor and its function is attached. Connect the sensor through a cable to the sensor ports (1, 2, 3, or 4).
3. Get into the "NXT program" on the panel.
    a. Turn on the panel by pressing the orange button
    b. Scroll right until you get to the "NXT program" and select it with the orange button
    c. The next screen tells you which port to connect each sensor to, and this can also be found in the attached instructions. (Note: only one sensor can be used for one task.) Press the orange button to continue.
    d. The next screen will prompt you to enter in commands into 5 different boxes.
        i. The first block allows you to enter in a direction (forward, forward 5, etc.)
            1. The number after a direction represents how many seconds it will move in that direction. If you choose one without a number, it will continue to move forever.
            2. What do the sensors do?
                a. Ultrasonic – Sensor is activated when it "sees" an object in front of it
                b. Touch – Sensor is activated when orange button is pressed
                c. Microphone – Sensor is activated when loud sound is heard (clapping, etc.)
                d. Light – Sensor is activated when a light or dark environment is seen
        ii. The second block allows you to enter in the sensor command
            1. "Object" – Ultrasonic sensor
            2. "Touch" – Touch sensor

3. "Dark" – Light sensor (dark colors)
4. "Light" – Light sensor (light colors)
5. "Sound" – Microphone
6. Or you can choose the "Empty" box, which will not involve using a sensor, and it will move onto the third block command

iii. The third block is another direction command
iv. The fourth block is another sensor/empty command
v. The fifth block allows you to choose to end the program or click loop, which will repeat the previous commands until the brick is turned off

e. After you put your commands in, press the orange button to run the program
f. To stop the program, press the dark grey button below the orange one.

4. Test your robot car to drive into and out of the specified space.

Activity 2:

Objective: Build and control a robot arm to move an object by an angle in the shortest time while maintaining balance.

1. Login in the computer using your PSU ID.
2. Download "lego_outreach.mdl" from Angel to your P-drive by right click. DO NOT open it directly from Angel. Make sure "Save as" in P-drive.
3. The teaching assistant will upgrade the software for you. (Notify the assistant when your group is ready. You do NOT need to do anything in this step.)
4. Listen to the presentation.
5. Build the robot claw and attach it to the NXT brick following the claw instruction. (You will need to dissemble your wheeled car to build the claw.)
6. Connect the NXT brick to the computer using the USB cable. Connect the base motor to the port B of the NXT brick, and claw motor to the port A of the NXT brick.
7. Adjust the controller parameter to rotate the arm and move the object in the shortest time.