Robotic Art for STEM

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ABSTRACT

In this paper, we describe our experiences in using geometric art to develop robotic skills in both undergraduate and high school students. The intent was to use robots to enhance interest in STEM (science, technology, engineering, and mathematics) disciplines among high school students and in system level design and integration issues in the undergraduate student population.

Keywords: K-12, STEM, Autonomous Robot, Education, System Integration

1. INTRODUCTION

In this paper, we describe our experiences in using geometric art to develop robotic skills in both undergraduate and high school students. Our undergraduate students developed a low cost robotic prototype with the primary goal to make it affordable to K-12 students and schools. The robots, of necessity, are made of imprecise mass manufactured components. This allowed the undergraduate students to consider system issues, and optimize with regard to cost, battery drain, ease-of-use, and performance. This process helped us identify a low cost kit that high schools can afford to purchase, and an assembly process that high school students can easily follow. We chose robotic art as the primary vehicle to expose high school students to robotics because of the social context such a team project can provide. Further, we chose to use geometric robotic art in an effort to limit the options, but also to emphasize the STEM aspects of robotic use. This semester's pre-engineering course for 9th graders has led to an even lower cost kit and an improved curriculum. These are fully programmed autonomous robots that execute the geometric pattern without any remote control from the student teams.

2. METHODS

The robotic kit used comprises of a DF Robot 2WD mobile platform, 2 DF Robot wheel encoders, Parallax Ping Ultrasonic sensor, Robotics DMS IR (infrared) Distance sensor, Arduino Uno microcontroller board, Arduino Protoshield, 2 H-bridge motor drivers, and a few other miscellaneous items, all secured from the two suppliers [www.robotshop.com, wwwe.sparkfun.com]. Arduino is an open source initiative that provides significant hardware and software support for embedded system designers [1]. Arduino's Sketch language and APIs provide programming support for the underlying microcontroller without exposing the user to the extremely complex and confusing register level details of the ATMega 328 microcontroller from Atmel [2]. The Arduino platform was developed primarily to aid the artists (to control the stage props, applause, music, etc., for example) without overwhelming them with the underlying electronics. Extrapolating, it seemed like a good fit for both our engineering undergraduate students (from computer science, electrical engineering, and computer engineering), so they could focus on systems issues, and for high school students who have limited or no programming and electronics skills.

Students work in teams of three and use a large canvas (80 cm by 80 cm sheet with greeting card thickness) to draw their art on. They use a color pen that could be mounted in the center of the robotic platform when needed. The robots have three wheels, with two motors that are driven (through an H bridge and a power amplifier) from the PWM (pulse width modulation) outputs of the Arduino Uno microcontroller. The robot also has one ultrasound ping sensor mounted in the front and two infrared sensors mounted on the two sides. The sensors are used to ensure that the robot travels on a straight line; this is achieved with reflector walls placed to make a 1 m x 1 m square fence. The wheel encoders provide 10 positive going pulses per turn. Student teams use Sketch to program their robots. Undergraduate engineering students used interrupts and achieved intricate geometric patterns [3]. We have intentionally restricted our 9th grade high school students to draw simpler patterns, but repeating in some way, so we can show how an algorithm can be reused with changes in parameters. The goal then is to make sure the algorithm is rugged and that it leads to repeatable results, and use this algorithm in different contexts to create the pattern. For example, a triangle involves two algorithms repeatedly used, viz., to draw a line, and to turn an angle. The first one will need two parameters: distance and angle, while the latter one will need one parameter: angle, with the angles referring to a standard coordinate system. Our work from fall semester with undergraduate students is well documented at our robotics website, with links to their blogs and their demo videos [3]. We used this robotic platform in a course (Intro to Mechatronics) taught to 9th graders this semester. Their blogs also may be accessed from our robotics site [3]. Their demo videos are available at their blog sites. A survey and an interview were conducted by one of the co-authors who is a professor in education to understand how effective our teaching was, from both Mathematics and Engineering perspectives.

3. RESULTS

3.1 Engineering pertinent experiences from our undergraduate level course:

This class, offered in fall 2011, had an equal number of students from computer science, computer engineering, and electrical engineering. Each team was typically comprised of one student member from each of these three disciplines. Such teaming helped them harness different strengths and also appreciate and accommodate different perspectives. Seven teams were formed. The students used a 1 m x 1m floor space with reflector walls encircling the space. The student blog sites and videos of their robotic art are available at our website [3]'s January 8, 2012 postings. Two teams focused on creating simple polygon patterns (a rectangle and a triangle); See videos of groups 1 and 6 [3]; this required effective use of the IR receivers and the ultrasound sensor for distance measurements, corrections for interference and potential avoidance of 'drunekn sailor' behavior of the robot because of the IR receiver characteristic in near field (more on this later). A third team (group 3) created intricate polygon pattern that was repeated a large number of times [3]. This required effective use of optical encoders and interrupts. The former did not yield clean ten pulses per turn, as would be expected. The electromechanical bouncing was evident even here and led to thousands of pulses. The students used back-to-back Nand gates and software delays to overcome the problem. Prioritization of interrupts had to be carefully thought through. Finally, while some teams complained of loss of precision in robotic movement when the batteries were somewhat drained, this group managed to create intricate patterns without losing control. Group 7 specialized in building a pen holder and the reflector walls that were used by other teams. The pen we had chosen was too bulky and the pend holder with pen ended up being a drag on the performance of the robot. Further, the use of four wheels caused large circles when the robot turned. It appears that other teams suffered because of lack of communication and coordination. However, we also recognized the need to help them plan and strategize; and also address issues in a piece-meal fashion. Experiences, both positive and negative, helped us identify a better kit and a focused syllabus when this material was used to teach a mechatronics course to high school students this semester (spring 2012).

3.2 Engineering pertinent experiences from our high school level course.:

This course attracted 17 ninth graders at the Henderson School, FAU's University School on our Boca Raton campus. These students are in their pre-engineering program. This was the second engineering program that they had taken. The students comprised of 11 boys and 6 girls, with strong aptitude for mathematics and engineering. Five teams of 3 or 4 students were formed and were asked to choose a geometric pattern of medium complexity to draw with their robots. Each team built their own robot and developed algorithms for drawing lines and rotating by given angles. This required calibration of their robot's wheels for the distance traveled (at different PWM duty ratios) in a given time period, and the length of the PWM train to make a complete circle (at different PWM duty ratios). To make such a tight circle, the outer wheel was subject to this PWM train, while the inner wheel was held stationary. One could make fairly precise angular turns by controlling the duration of the PWM train. Different groups needed angles of 45, 60, 72, or 90 degrees depending upon the mathematical shape they were creating. Our initial goal here was to have the student teams use the reflector walls along the fence as guideposts; but the IR receiver characteristic has a negative slope in the near field. So, any simple algorithm that checks for a large reading from the near side IR sensor to keep the robot away from that wall ended up making the robot end up at the wall. It was difficult to convey a more sophisticated algorithm to the student teams because of the time pressure to get a working prototype completed. Another way would have been to use ultrasound sensor to measure the distance from the front wall and use that to correct the robot's path. Time pressure precluded us from incorporating either. Thus the final student implementations ended up being 'deaf' to the surroundings that executed their motions purely based on control of the motors with PWM trains and different duty ratios. The five teams implemented four different patterns (Trinity force of courage, Butterfly, "FAU", and Star). Links to their blogs and demos are provided in the February 21, 2012 posting at our robotic site [3].

3.3 Other activities

One of the co-authors, with the college of education, interviewed five of the students who had signed the IRB form agreeing to the study. He interviewed them at the end of the semester in groups of 2 or 3 with the intent to see whether the course made any significant difference in the student's understanding of the underlying Mathematics and Engineering principles. Results from this study will be published at an ASEE conference to be held at the University of Texas, El Paso, TX.

4. DISCUSSION

(1) We have taught project oriented courses for a number of years. The emphasis, before this spring semester, had been to give lectures, and institute a few quizzes, but essentially allow the teams to develop the project on their own. However, unlike the robotics course, the earlier groups (in non-robotics oriented courses) had the benefit of projects completed by even earlier groups of students; that facilitated the thinking of that term's students. However, this was missing for the fall 2011 students taking our robotics course, and some of their projects suffered. We changed our approach to teaching such project oriented courses this semester. The first half of the semester is now focused on the theory during the lecture hours, while they build the robots during the lab hours. Several quizzes and a mid-term exam evaluated the students on the lecture and lab material. This ensured that the students had an acceptable minimum level of understanding and competence when they started the project in the second half of the semester. The students also had a clearer idea of how they were faring in the class. The younger high school students may also have needed reinforcement of the ideas. Either way, it appears that we were able to help them in successful completion of their projects. This was a significant improvement over the results from the fall 2011 semester with our undergraduate students from three different disciplines. (2) The high school students, under time pressure, discarded our recommended approach for use of infrared and ultrasound sensors and designed their algorithms merely based on control of distance traveled and angle turned. Successful completion of their projects is proof that high school projects can be undertaken with a simpler

robotic kit. This brings down the cost from about $160 per kit (currently) to about $100, our targeted price point that should be met for schools to afford the robots. (3) The high school students seem to have had problems with soldering, and thus had to use breadboards to connect wires from motors (and sensors) on to the Arduino Photo shield and the Arduino microcontroller board. It appears that we will use, in future course offerings, wire-wrap technology to make semi-permanent connections and avoid the potential for one of the bread-board wires to pop off and cause malfunctioning of the system. (4) Battery drainage was blamed by one student group for not drawing their star with proper angles, thus leading to a gap at the end. This group used 100% duty ratio and tried a large size star. Another team that drew a smaller sized star completed without any problems. (5) All these issues provide enough research material for an undergraduate robotics course in engineering at a later date. We expect to focus on building components or subsystems that can aid expansion of robot's role in STEM education for high school students. Possible examples of this are: robust sensor sub-systems for tracking; optical encoder-based interrupt driven sub-system for angular turns; and graceful slowdown based on battery voltage fall—off characteristics.

5. CONCLUSIONS

NSF (National Science Foundation) has launched a new initiative entitled CE21 (Computing Education for the 21st Century) [4]. Researchers at other institutions have explored the use of Java, Processing, and Python to expose K-12 students to computer education. We provide here yet another programming paradigm based on robotics and the Sketch language that has the potential to provide a social context and attract non-STEM oriented students to the STEM fold. Learning programming with robots has the advantage (compared to the above cited programming languages) of providing a social context and a hands-on experience. However, commercialization of robotics has priced the robots too far beyond the point of affordability for K-12 schools. We believe we can build low cost robots that schools can afford. We have presented our experiences in that regard here.

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7. REFERENCES

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