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A Multidisciplinary Undergraduate Project: Development of an Autonomous Rover For Mars Exploration

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Abstract

Few problems in engineering can be solved with a single tool. According to the Washington Accord [1], skills to solve complex problems in engineering are important to include in the curriculum of engineering education programs. To provide more experiential learning experience, the School of Engineering and Applied Sciences at the University of the District of Columbia (UDC) is modernizing its curricula by offering complex engineering training to its students through curricular and extracurricular activities.

The design of autonomous vehicles requires a collaborative effort from nearly all STEM fields and hence provides an excellent opportunity for engineering students of various backgrounds to collaborate on. During the Summer of 2018, a group of students from Electrical, Mechanical, Civil and Computer Science departments at UDC were recruited to work on an interdisciplinary project: design and develop an autonomous rover for Mars exploration. This group of students were supervised by two faculty members from Electrical and Mechanical Engineering. The team explored solving problems of Martian planetary exploration from the perspectives of mechanical, civil, and electrical engineering.

In this project, a multidisciplinary group of students were offered a unique opportunity to work closely on a tightly integrated system: an autonomous rover was designed, powered by solar energy, and a custom lithium-ion battery array was used to power a primary electric motor, microcontrollers, a steering motor, a linear actuator and a variety of sensors; to emulate the type of data an interplanetary rover may collect, the vehicle was outfitted with VOC and CO_2 gas, humidity and temperature, and proximity sensors. Proximity sensors were included for safety, to signal the need for automatic braking, as the most critical aspect of an autonomous driving system is to prevent collision. Sensor data was transmitted to an onboard computer via an XBee DigiMesh radio module. Two robotic arms powered by lithium ion batteries, and compatible with an Arduino platform, were installed on each side of the rover and the robotic arms were programmed to maneuver remotely. A customized housing for the proposed sensors, robotic arms, and solar panel were designed using computer-aided design software.

Throughout this project, team members often worked on problems outside their study area and gained valuable insight into creating something as complex as a Martian rover. Such highly integrated systems require the coordination of multiple fields of study with the goal of working on coordinated research with an interdisciplinary team. This paper gives details on the students' design, their learning experiences, and how experiential learning has been integrated into the engineering and computer science programs at UDC.

Introduction

In 2020 alone, there will be three rovers headed to Mars engineered by NASA [2], the European Space Agency [3], and the China National Space Administration [4]. These unmanned missions serve as a prelude to manned exploration of the red planet and subsequent colonization efforts by both public and private entities [5] NASA's journey into air and space has not only deepened humankind's understanding of the universe but it has also inspired and motivated millions of students to pursue careers in science, technology, engineering, and mathematics (STEM). Since 1994, NASA has sponsored an annual competition for high school and college students to design, build, and race human-powered mars rovers. These collapsible vehicles must navigate simulated outer space terrain, engaging students and providing valuable experiences in the technologies and concepts that will be needed in future exploration missions [6] In April 2018, the team from the University of the District of Columbia (UDC) entered the competition, yielding valuable insights into design, fabrication, testing, and the intricacies of systems engineering for the competition team.

This design competition provided an excellent environment for experiential learning and developing team leadership for the student participants. As such, this summer project on "Designing an Autonomous Mars Rover" was developed to expand the skills obtained in the rover challenge. With advances in autonomous vehicles and the need for rovers with higher degrees of autonomy to further scientific research goals, a team was created to help with the design and construction of an autonomous rover with wireless sensing capabilities which could conceivably operate on the Martian surface. The autonomous rover build team consisted of students from the fields of mechanical engineering, civil engineering, electrical engineering, and computer science. In this case, the team was led by a mechanical engineering junior and an electrical/mechanical double major junior who had both worked on the previous project. Students with expertise in coding, electrical engineering, and fabrication were brought in to complement the other mechanical skills. Class year was not a primary determining factor for team composition, as freshmen and rising seniors alike collaborated on this project. The team composition by major was as follows: ME: 5 students, CE: 1 student, EE: 2 students, CS: 2 students. Generally students offered expertise in field, for instance ME students assisting with mechanical design and construction, or CE students working on items like rock abrasion or soil mechanics, however the structure allowed all students to understand how their contributions shape a project with a larger goal. In particular, this project aimed to ensure underrepresented groups obtain a well-rounded, quality education. As a minority-serving institution, UDC strives to offer inclusive and fulfilling learning environments in preparation for both post-baccalaureate jobs and graduate programs. Such hands-on efforts are more likely to help those with a non-conventional secondary education than a pure classroom environment. [7]

Project Structure

The team was composed to maximize group input and collaboration and allow the students to approach the design challenges from the perspective of a systems engineer, looking at the design holistically. The project was broken into three broad categories – mechanical systems, electrical systems, and control systems. The team co-leads established the framework for construction and order of operations while integrating input from students with expertise in each area. Subgroups were formed to focus on specific aspects of the rover, such as wiring. For example, an electrical engineering student oversaw completing the wiring with the assistance of students from other engineering fields. Make it more complex, modifications to the autonomous rover's frame may impact sensor placement, wiring, or power requirements. Components such as the robotic arm often required substantial group collaboration between students creating a mounting platform and designing sampling instruments and the electrical engineers and computer scientists creating working code so the arm could achieve design goals. Furthermore, students were expected to gain practical machine shop skills such as welding, use of the milling machine, electrical wiring and circuit design, and additive manufacturing through fused deposition modelling (FDM) to complement their collaborative work.

After assessing the resources available and the time frame of this project, the student team chose to use an existing vehicle frame to reduce development time and ensure a structurally sound platform for conversion to an electric vehicle:

1. The team modified a go-kart frame, dubbed the "Smart Kart," which could, with minimal modifications, accept automatic braking, an electric motor, and other facilities to enable a speedy buildout.

2. Given the prefabricated nature of the go-kart, the mechanical systems were largely in need of modification for robotic control as steering and brake systems were preexisting. This included robotic steering control, mounting a linear actuator to affect the brakes, creating a mount for the battery pack, motor, and robotic arms, and designing the 3D models used for subsequent FDM using polylactic acid (PLA) and nylon plastics for the various mounts and sensor housings. Importantly, the experts in coding and electrical systems could determine how the components they would be designing would need to function in a finished product.

3. Command and control used off-the-shelf parts, namely Arduino Mega 2560s in a master-slave configuration, to enable wireless control and sensor feedback to a control station via an XBee radio unit. Leveraging these relatively inexpensive and readily available microcontrollers further reduced development time and overall system complexity due to the large number of Arduino-compatible sensors and existing documented C code. True autonomy with computer learning was outside the scope of this project, particularly given the Arduino hardware, however preprogrammed routes with object detection was feasible and implemented in the final hardware.

Parts and Equipment

The students were given a budget with which to meet all necessary design goals. At just over $1,500, they were able to assemble and test the vehicle, as seen in Figures 1 and 2. Table 1 lays out these parts and respective pricing, as created by the student team.

Table 1. Parts list

Part	Number	Unit Cost	Shipping	Total Cost
LG Li-Ion 18650 2.6 Ah	121	$2.99	$12.00	$373.79
Complete 1800w 48v Motor Package W/Foot Pedal (Go Kart)	1	$289.00	$15.35	$304.35
Smart Charger (3.0A) for 37V Li-ion/Polymer Rechargeable Battery Pack --- CE Listed*	1	$69.95	$19.81	$89.76
Inland Arduino Mega	3	$9.99	$0.00	$29.97
SainSmart 6axis robotic arm	2	$169.99	$0.00	$339.98
ECO-WORTHY 10W Solar Panel 10 Watt 12 Volt Pv Solar Module,Solar Cell Panel	4	$24.99	$0.00	$99.96
Solar charge controller (48V)	1	$65.99	$0.00	$65.99
30A, 60V MOSFETs (10)	1	$16.88	$0.00	$16.88
MG-811 Gas CO2 Carbon Dioxide Sensor	1	$49.99	$0.00	$49.99
37-in-1 Arduino Sensors Kit	1	$29.99	$0.00	$29.99
Xbee s2c XB24CDMWIT-001	2	$17.50	$7.99	$42.99
4 Inch 4" Stroke Linear Actuator 12 Volt 12V 225 Pounds lbs Maximum Lift,Black	1	$37.79	$0.00	$37.79
[8-PACK] LM2596 DC-DC Adjustable Buck Converter 3-40 V to 1.5-35v Step Down Power Supply High Efficiency Voltage Regulator Module …	1	$11.99	$0.00	$11.99
CJRSLRB Gas Detection Module MQ-2 MQ-3 MQ-4 MQ-5 MQ-6 MQ-7 MQ-8 MQ-9 MQ-135 Sensor Module Each of Them 1pcs total 9pcs Sensor kit	1	$26.99	$0.00	$26.99
Breynet 3M 0.1 x 8 mm 18650 Pure Ni Plate Nickel Welding Strip Tape 3 M For 18650 Battery Spot Welder / Welding	1	$5.99	$0.00	$5.99
Cylewet 10Pcs 100K Ohm NTC 3950 Thermistor, Temperature Sensor for 3D Printer (Pack of 10) CYT1064	1	$7.28	$0.00	$7.28
VRUZEND battery kit V1.5	2	$31.99	$19.33	$83.31
Large diameter battery heat shrink (1ft)	10	$2.99	$0.00	$29.90
Cllena Dual Battery Selector Switch for Marine Boat Rv Vehicles	1	$29.99	$0.00	$29.99
				Total
				$1,676.89

Figure 1. The Smart Kart front view, with visible ultrasonic sensors, robotic arm, steering assembly, and 40W solar panel array

Figure 2. The Smart Kart side view, with visible battery array, 1.8kW motor, and solar charge controller

Selecting the parts was a collaborative process, as with other aspects of the progress; given the experience of some team members, they were able to eliminate unnecessary expenditures and optimize the parts selected for the build.

Testing

The Smart Kart was tested both on the ability of the rover to drive various routes and on the functionality of the sensors and robotic instruments. Moving tests, such as driving forward, reversing, braking, and turning, demonstrated the ability of the Smart Kart to follow pre-programmed routes with complexity limited only to the available storage space for code on the Arduino Mega 2560 microcontroller. During all moving tests a safety driver remained seated in the vehicle with the capability to override steering, brake, and accelerator input.

Sensors and robotics were tested using a laptop base station which communicated with the onboard sensors via an XBee wireless radio unit connected to the Arduino microcontroller. Preprogrammed sampling and data return via the XBee wireless radio unit were tested and fully functional in the finished product. Data such as temperature, humidity, pressure, and CO_2 and VOC gas concentration were communicated back to the base station. Commands could also be sent to the pair of robotic arms; one arm was outfitted with a drilling tool capable of rock abrasion and soil drilling which successfully abraded a concrete sample. Automatic collision detection and braking was not fully implemented due to issues with reliable ultrasonic collision sensor readings. This would likely be mitigated with the use of a secondary or backup sensor such as a laser range finder or infrared sensors, proving a valuable lesson about the value of redundancy in highly integrated systems.

Learning Outcomes

There are few adequate substitutes for experiential learning in an applied field such as engineering. While classroom learning and simulations are critical in ensuring students obtain a foundation of knowledge, they cannot replace group problem-solving with actual hardware. [8] For example, the team had considered using a linear actuator control system for the throttle operated via a pedal which manipulated a potentiometer. A mechanical engineering student experienced with Arduino suggested instead using a pulse width modulation (PWM) signal to mimic the potentiometer signal, reducing overall cost and complexity of the system. This kind of resourceful problem-solving would have been less likely in a classroom or simulated setting.

While modeling and simulation are both critical learning tools for students, they can only serve as a simplified picture of the realities faced by a real engineer [9]. Parts will break, wiring will short out, and programs will encounter unexpected errors; the ability to overcome these challenges is fundamental to a successful career in engineering.

A survey was conducted to see how this multidisciplinary project has helped students in “an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives” (new ABET Criteria 5).

The School of Engineering and Applied Sciences at UDC has seen an increased number of multidisciplinary senior design projects where students and faculty collaborate. The data from these surveys are valuable to the instructors as it helps them get insight of how projects such as the one conducted can help students better function as members of a multidisciplinary team and what aspects of new Criteria ABET 5 would require more training.

Table 2. Survey form for the team members

This survey is to see how this multidisciplinary project has helped you in “an ability to function effectively on a team”. Please indicate by checking the boxes that indicates how well you feel that you have mastered the objective.						
What is your perception of your personal mastery of:		Select one choice only				
		Poor (1)	Fair (2)	Good (3)	Very good (4)	Excellent (5)
Q1.	Function as a member of multidisciplinary team; identify a need and prepare a design proposal for approval of instructor					
Q2.	Specify design specification; establish design requirements; conduct a feasibility assessment; perform qualitative synthesis of design solution with inputs from all team members					
Q3.	Manage, plan and schedule the design effort; demonstrate sound compromise in decision making					

Q4.	Perform design analysis for material selection; articulate the principles of concurrent engineering through production, planning, manufacturing, etc					
Q5.	Perform functional cost analysis; understand product integration and systems engineering					
Q6.	Inculcate safety, reliability, and environmental impact into the design process; demonstrate sound judgment and show appreciation for social and political factors					
Q7.	Demonstrate effective communication using graphic, written, and oral media; demonstrate ability to use modern engineering tools in design					
Q8.	Prepared for additional extra-curricular activities and senior capstone design projects					

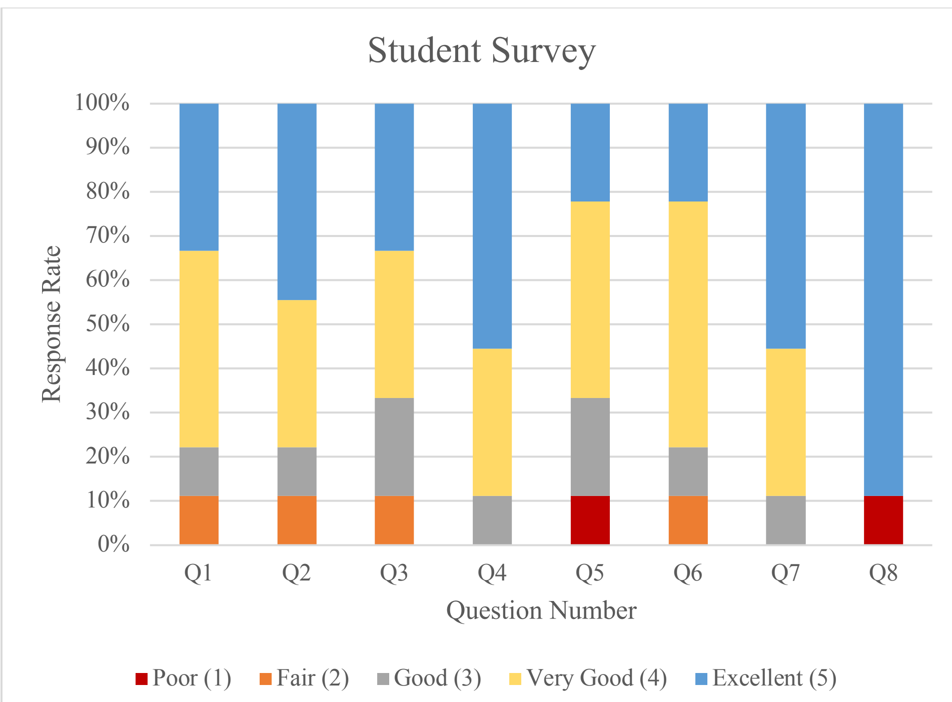

Figure 3. Student survey results

Of the 10 students involved in the project 9 responses were received with the results as seen in Figure 3. The feedback collected through this anonymous survey, has clearly shown the advantages of implementing this multidisciplinary project as an extracurricular activity that it can engage students and foster experiential learning: all the student participants highly valued this project and 89% think this project was helpful in preparing for their senior capstone design projects.

In addition to providing a valuable hands-on learning experience for the students involved, the rover project has been used as a recruitment tool for attracting students to other multidisciplinary design projects and the engineering program at large. Harnessing the growing interest in self-driving technology and interplanetary exploration has proven a valuable draw for students to pursue a STEM degree. For instance, the rover project was used as a showcase for first year students in their Intro to Engineering course to demonstrate the types of projects available for them to work on in the coming semesters.

Conclusion

UDC set out to create an autonomous rover suitable for simulated Martian environments in an effort to improve student leadership skills, group collaboration, and obtain hands-on learning experiences. Based on the survey results received to date, the data indicates students have a higher ability to function as a team member, have greater understanding of systems engineering, and generally felt the project was very good for all indicators while no students rated their mastery as fair or poor. In the future, the engineering program intends to continue to study the impact of interdisciplinary experiential learning activities as a means to foster enhanced ABET Criteria 5 outcomes.

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