AC 2012-4883: TOUR GUIDE ROBOT: A PLATFORM FOR INTERDISCIPLINARY ENGINEERING SENIOR DESIGN PROJECTS

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Tour Guide Robot: A Platform for Interdisciplinary Engineering Senior Design Projects

Abstract

Interdisciplinary projects involving electrical engineering (EE), mechanical engineering (ME), and computer science (CS) students are both exciting and difficult to conceptualize. Answering this challenge, this paper presents an interdisciplinary project platform based on tour guide robots. The combination of software, hardware, and mechanical design makes this platform an excellent choice for undergraduate student projects in both design and research aspects. This integration of complex programming, electrical hardware, and mechanical system design provides an excellent educational experience for undergraduate students.

Also, this interdisciplinary platform is systematic and integrated that involves investigating a complex process or system with multiple design and research elements, such as wireless communication, control system design, statistical analysis, structural dynamics, and design for manufacturability. Through working on this project, students will be able to study a complex engineering and technology system that: (1) exposes them to applied and cutting-edge technologies; (2) encourages them to participate in an integrated, interdisciplinary curriculum; and (3) involves them in methods of applied technology and skills necessary to transition from academic to professional environments.

1. Introduction

Rapid advancement in technology has laid a path for the design and manufacture of many interdisciplinary integrated technologies. These advancements have provided new avenues for the engineering educators to better prepare tomorrows global citizens through methods capable of responding to the challenges of tomorrow[1]. On the other hand, the number of individuals/prospective students pursuing Science, Technology, Engineering, and Mathematics (STEM) professions in United States (US) is far less when compared to developing nations. For the US to continue being the global leader in engineering and technology, engineering educators need to be proactive in preparing engineering graduates through interdisciplinary integrated approaches.

One significant methodology that can be used to prepare these engineering graduates is actively engaging them in interdisciplinary projects that model professional collaboration; highlight the significance of engineering and technology, and their contributions. Tour Guide Robot (TGR) is one such platform that can be used for interdisciplinary projects in STEM disciplines. Rooted with the key disciplines of electrical engineering, mechanical engineering, computer science, and industrial technology, the TGR projects can teach students how to collaborate, while being able to demonstrate their contributions in a short time.

2. Significance of Interdisciplinary Teams

The conventional senior design projects in the engineering curriculum have substantial drawbacks such as limiting the bounds to just one discipline and focus on improvement rather than innovation. A student-focused curriculum should be designed to address some of these drawbacks. Undergraduate education is a stimulation and nurture process where students are open and eager to learn new things. It is up to faculty mentors to provide opportunities and actively engage these students. Engineering education, on one hand requires the adaptive grasping of basic theories, and on the other hand, emphasizes hands-on experiences, innovative ideas and creativity that meet societal needs. There is a genuine necessity to bridge the gap between theory and practice. A practical approach is to improve student participation in innovative design methods and education.

Two critical success factors for an engineer in the "flat-world" are their ability to adapt to changes, and be able to work at the interface of different disciplines[2]. In this "flat-world"[3], engineers and scientists need to constantly absorb and teach others new ways of doing old or new things, and mostly learn how to work well with others. By working with others, students: (a) obtain opportunities to experience a different domain; (b) combine knowledge and skills from different disciplines; (c) work as a team member; and (d) solve real-time research problems. Also, interdisciplinary collaboration provides students with significant personality development opportunities[4].

ABET describes that engineering programs focus on theory, and engineering graduates spend their time planning, while technology programs focus on application and technology graduates spend their time making plans work[5]. An interdisciplinary collaboration of engineering and technology students on research and design projects answers some of the challenges in this "flat-world". Additionally, this platform is in accordance with the National Academy of Engineers recommendation that, "Engineering schools should introduce the interdisciplinary learning in the undergraduate environment, rather than having it as an exclusive feature of the graduate program"[1].

One of the primary advantages of interdisciplinary teams is that instead of each student team requiring initiation of the project from ground zero, they can work on the project based on a platform that has been initiated previously. This provides ample time for the students to deal with integrated and complex projects, and have a deeper understanding of new concepts. Overall, the interdisciplinary projects such as tour guide robot can cover several focus areas in the engineering and technology disciplines as shown in Figure 1.

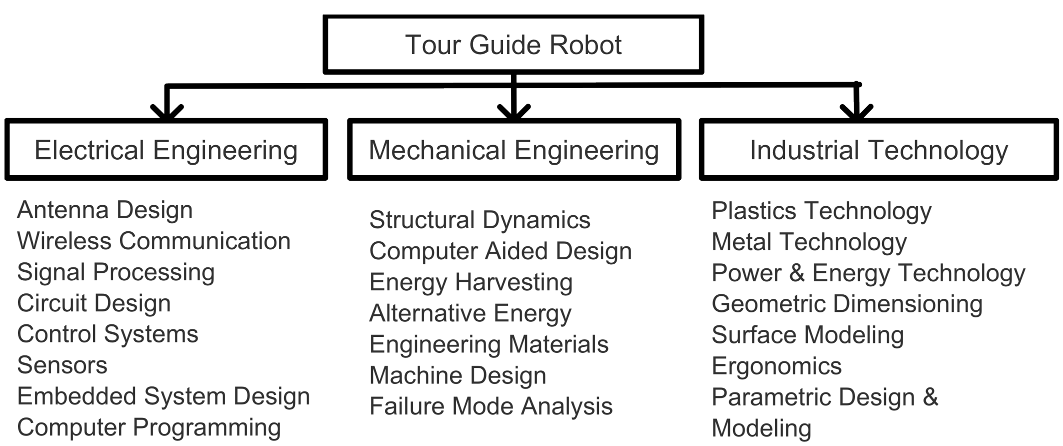

Figure 1: Technical Focus Areas Covered in the TGR Project

3. Design and Implementation

3. 1 Concept Development

Most robots have a set of standard components: a movement mechanism, a casing to organize and protect design components, a controller to serve as the brain, and some form of feedback system. Specific categories considered for formulating design concepts are base components, base dimensions, physical appearance, and method of localization and navigation, and feedback system. This analysis method led to formulation of different concepts as in Table 1.

Table 1. Tour Guide Robot Design Concepts

	Concept A	**Concept B**	**Concept C**	**Concept D**
Base				
Wheels/Axle	Two Wheels in Front, One in Back	Two Wheels in Front, One in Back	Four Wheels (Two on each side)	Four Wheels (Two on each side)
Motors	2	2	4	4
Shape	Circle	Square	Square	Square
Dimensions				
Width (m)	0.33	0.75	0.33	0.75
Depth (m)	0.33	0.75	0.33	0.75
Height (m)	1.5			
Physical Appearance				
Outer	Cylinder w/flat top	Rectangular Prism w/flat top	Cylinder w/flat top – outside the wheels	Rectangular Prism w/flat top – inside the wheels
Frame Material	PVC (plastic)	Metal	PVC (plastic)	Metal
Additional Features	Window for Computer Monitor Plexi-glass Strip to Showcase Design			
Navigation				
Obstacle Detection Sensors	Combination of Infrared & Ultrasonic Sensors			
Obstacle Detection Degree	180/180			
Obstacle Detection Placement Height	Parallel to ground at an altitude of 0.15 meters Parallel to ground at an altitude of 1.00 meters			
Path Detection & Localization	Radio Frequency Identification (RFID)			
Controller	Motorola Dragon12-plus			
Audio/Visual Output				
System	Laptop Computer			

Each concept was evaluated based on the scoring matrix in Table II. The evaluation criteria were generated from the customer needs and engineering specifications provided. With stability and reliability being of highest importance, it was assigned a weight of 25%. As the operational accuracy determines the overall quality of the product developed, it was assigned a weight of 20%. As power consumption, durability, ease of importance, and mounting style were given moderate importance by the customer, they were assigned a weight of 10% each. With some of the parts necessary available, cost was not of primary concern. Accordingly, it was assigned a weight of 8%. Later, a ranking in the range of 1-5 (1-low importance, 5-high importance) was assigned to each criteria based on customer needs. With the weight and ranking assigned, a weighted score (weight x ranking) was computed for each criterion, to find the ideal design concept.

The design chosen (Concept-B) for the Tour Guide Robot utilizes a built-from-scratch tri-wheel design featuring two drive wheels and a third stabilizing wheel as shown in Figure 2. The obstacle detection was achieved using a combination of infrared (IR) and ultrasonic sensor arrays located at multiple levels on the rectangular outer shell. The chassis was constructed of sheet metal. Two 200 mm diameter wheels powered by 35.8 mm DC motors were used for movement. A single castor wheel was placed near the rear of the robot. The rear of the robot was covered in 6mm plexi-glass to ensure that the lap top computer screen can be clearly seen.

Table 2. TGR concept scoring matrix

		Concept A		Concept B		Concept C		Concept D	
Evaluation Criteria	**Weight (%)**	**Ranking (1 – 5)**	**Weighted Score**	**Ranking (1 – 5)**	**Weighted Score**	**Ranking (1 – 5)**	**Weighted Score**	**Ranking (1 – 5)**	**Weighted Score**
Power Consumption	10	4	0.40	3	0.30	4	0.40	2	0.20
Cost	8	3	0.24	4	0.32	2	0.16	3	0.24
Durability	10	3	0.30	4	0.40	3	0.30	5	0.50
Operational Accuracy	20	3	0.60	4	0.80	3	0.60	4	0.80
Ease of Implementation	10	3	0.30	5	0.50	3	0.30	5	0.50
Mounting Style	10	2	0.20	5	0.50	2	0.20	5	0.50
Aesthetically Pleasing	7	4	0.28	3	0.21	4	0.28	3	0.21
Stability	25	2	0.50	5	1.25	2	0.50	5	1.25
	Total Score		2.82		4.28		2.74		4.20
	Rank	25		33		24		31	

*Ranking based on scale (1-5) 1 being least desirable, 5 being most desirable

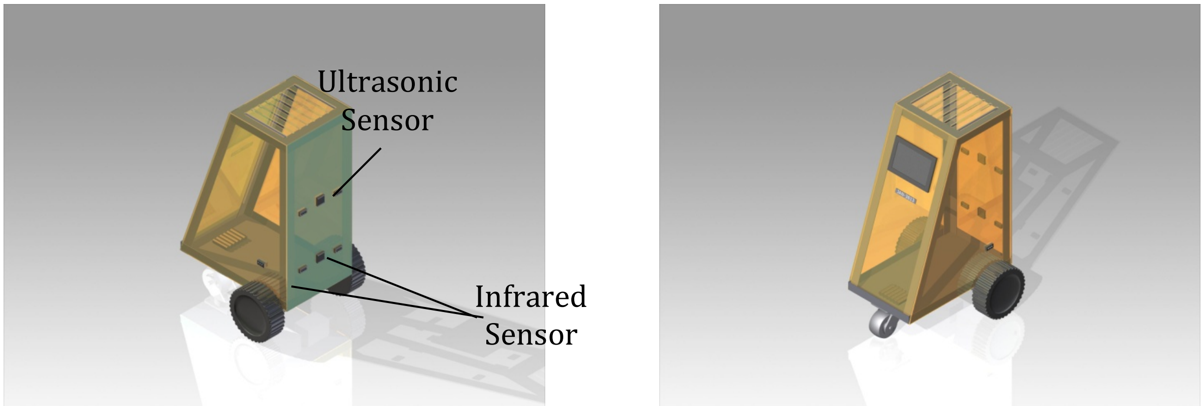

Figure 2. Final Tour Guide Robot Design Concept

The DC motors, ultrasonic sensors, IR sensors, RFID system, laptop computer and wireless remote were interfaced using a Dragon 12-Plus[6] microcontroller. A shelving unit was implemented so that all necessary components may fit at desired areas within the shell. The laptop computer, speakers, and remote were placed on the higher shelf so the audience will be able to view the screen at the best possible angle. The battery and microcontroller were placed on the bottom shelf along with the RFID system[7]. Figure 3 shows the embedded system that serves as the brain of the TGR. Information on current location and obstacles in the robot's path of travel is transmitted from the input module to the microcontroller. This information is used by the microcontroller for appropriate actions, which then transmits data to the output module to display relevant tour information, and for safe navigation.

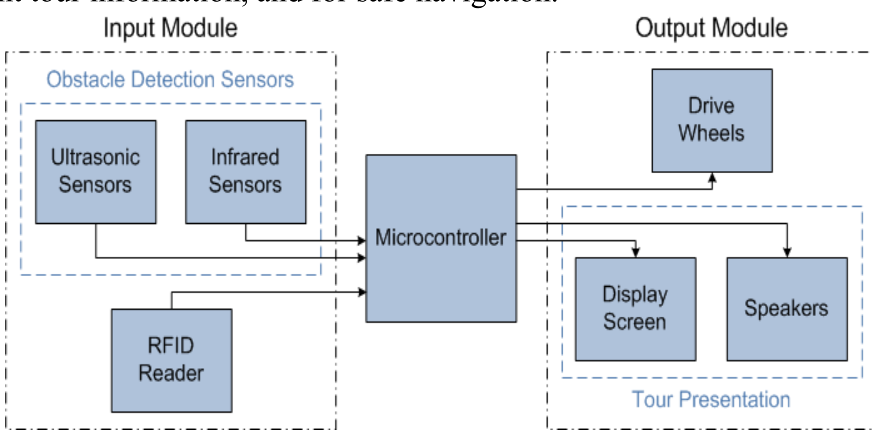

Figure 3. Embedded system of the tour guide robot

3.2 Obstacle Avoidance Sensors

In order to find the best obstacle detection method, ultrasonic[8] and IR[9] sensors were researched and compared as shown in Table 3. The weight criteria are based on the customer needs in avoiding obstacles. While the ultrasonic sensor was able to detect obstacles as far as 16 feet away, the IR sensors were able to detect obstacles only up to 8 feet. Also, while the ultrasonic sensors have a scanning range of 45^O to 60^O, the IR sensor send only a single beam of straight light to detect the obstacle. Accordingly, ultrasonic sensor has been assigned high weight in sensing angle, when compared to the IR sensor. However, the IR sensor consumes less power when compared to ultrasonic sensor. Overall, with each sensor having their unique advantages, a combination of ultrasonic and IR sensors were used in the project.

Table 3. Obstacle detection sensor scoring matrix

Selection Criteria	Weight (%)	Ultrasonic Sensor		IR Sensor	
		Ranking (1-5)*	**Weighted Score**	**Ranking (1-5)***	**Weighted Score**
Sensing Distance	20	5	1.0	3	0.6
Sensing Angle	20	5	1.0	1	0.2
Accuracy	20	5	1.0	5	1.0
Reliability	20	5	1.0	5	1.0
Cost	10	2	0.2	5	0.5
Power Consumption	10	3	0.3	5	0.5
	Total Score		4.5		3.8
	Rank	25		24	

* 1 – low importance, 5 – high importance

Two Daventech SRF04 Ultrasonic Range Finders and five Sharp IR sensors were used in combination to create an efficient obstacle detection system as shown in figure 4. Here the dashed segments (black color) represent an ultrasonic sensor and a solid segment (red line) represent the IR detection range. The course correction area (blue color) measures 1.210 meters in front of the robot. When the TGR detects an obstacle in this course correction area, the obstacle avoidance algorithm will engage to redirect it accordingly.

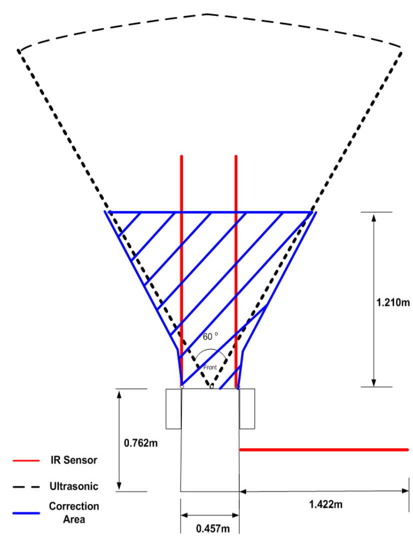

Figure 4: Obstacle avoidance sensor placement

3.3 Navigation

Navigation algorithm for the TGR with functionality of each sub-routine (obstacle avoidance, localization, and path correction) is shown in figure 5. The TGR has sensors on the front to detect when an obstacle is present in its intended path. If an obstacle is detected in the course correction area, the obstacle avoidance sub-routine will activate, stop the robot, and turn it left 90°. It will then utilize the right side IR sensor to monitor the obstacle's position. Following the turn, the robot continues to move forward, tracking its distance covered as variable *x*, until the right side IR sensor no longer detects the obstacle and turns right 90°. It then moves forward parallel to the obstacle, until the right side sensor no longer detects the obstacle. The robot then performs a 90° right turn, and travels distance *x* to return back to its intended path, where it turns 90° left and continues forward as shown in figure 6.

Localization is the process by which the TGR is able to recognize its position within its operating environment. This localization was performed with the aid of the RFID system. Passive RFID tags were loaded with some information, and placed along the hallway, and an RFID transponder was mounted on the TGR. While the TGR is navigating in the hallway, if it detects a tag, it pings the tag to obtain the necessary information. The information obtained (Electronic Product Code) was compared to data stored in the look-up table to determine the appropriate actions to be taken as in figure 7. These actions would include navigation and tour cues for the microcontroller to interpret and control sub-systems accordingly.

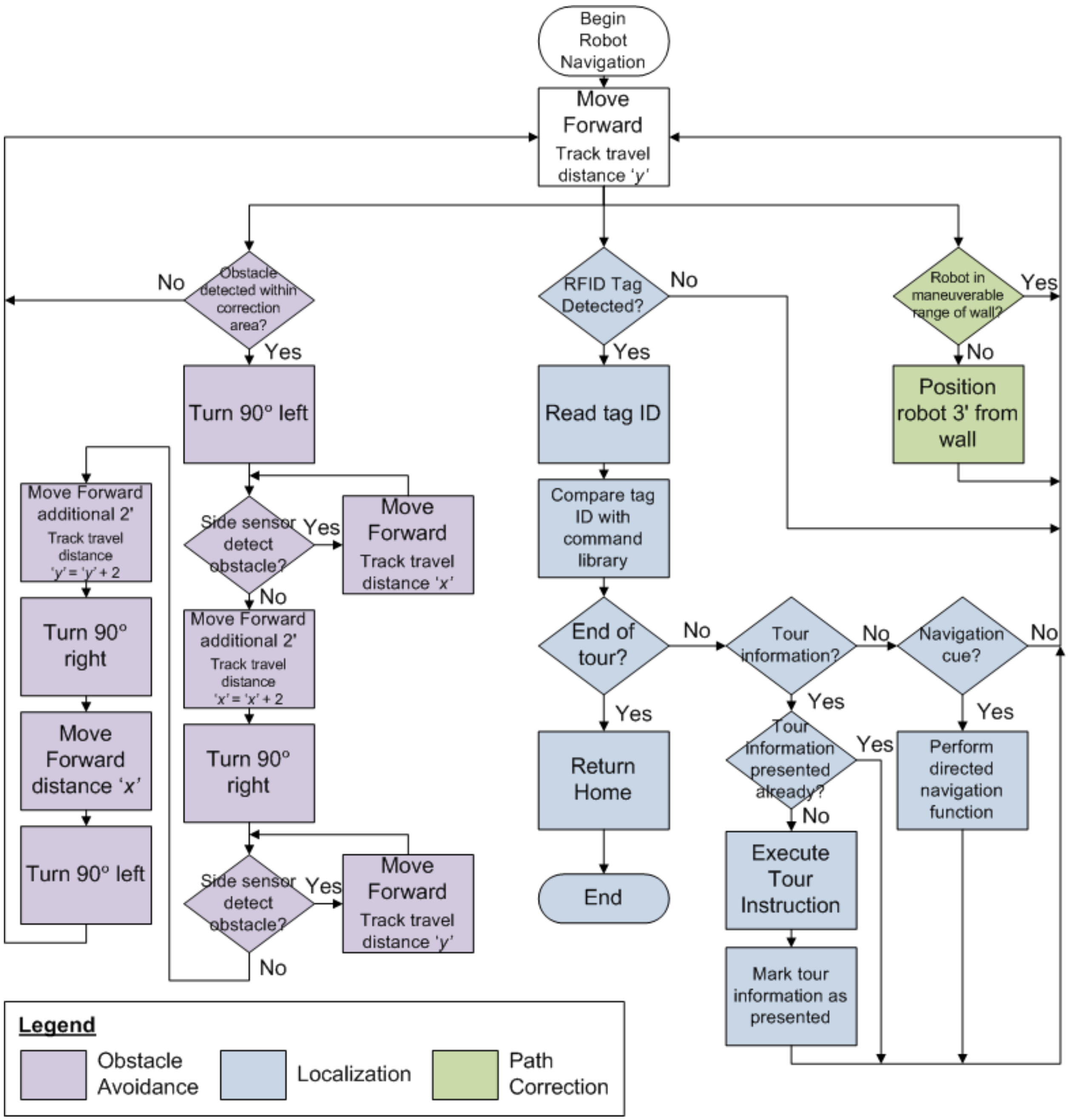

Figure 5: TGR Navigation Algorithm

For path correction, the TGR utilized a wall following algorithm. One IR sensor was placed on the right side of the robot, and senses its distance to the wall. When the TGR is within the maneuverable range of the wall, it continues its normal navigation. When the robot gets too close or too far away from the wall, the path correction sub-routine engages and directs the TGR back on track as shown in figure 8.

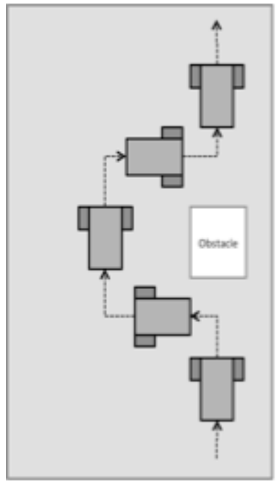

Figure 6: Obstacle avoidance

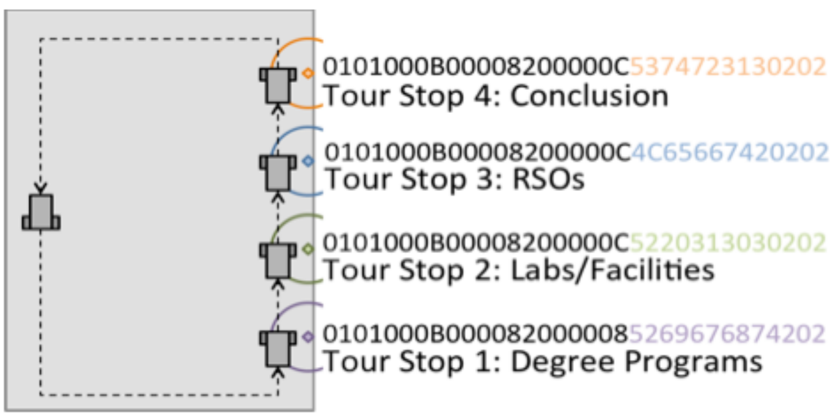

Figure 7: RFID based localization

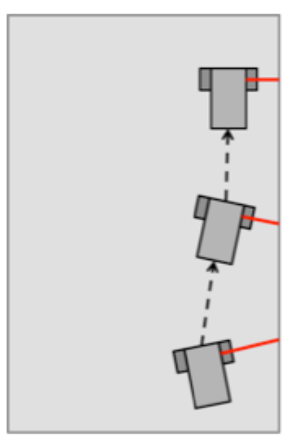

Figure 8: IR based path correction

4. Tour Guide Robot Projects and ABET Criterion

While this project was implemented in the class, and students were found to be receptive, it is imperative that it meets the ABET Criterion 3 requirements[5] addressing the skills, knowledge, and behaviors students should have at the time of graduation. This section outlines how this project meets this criterion briefly.

4.1 Demonstrate the ability to apply knowledge of mathematics, science, and engineering

With the TGR project requiring collaboration of students from multiple disciplines, it is a good platform to nurture knowledge in mathematics, science, and engineering during design and implementation. Specifically in EE, students can nourish their skills in signal processing and communication such as interference and shielding, antenna-gain, length, angle, multiplexing, placement, polarization, propagation pattern, resonance, and tuning, crosstalk, multipath fading, Faraday's Law, Gauss's Law, signal modulation, circuit design, and programming of an embedded system. In ME, TGR project nurture student skills in force calculation, friction, concurrent forces, moments of inertia, kinematics, work and energy calculations, stress and strain theories, loading and deformation, power transmissions, and kinetics etc.,

Although the listed topics are logical and straightforward in each discipline, the TGR requires the application of topics from multiple disciplines together towards completion. This allows students from other discipline to gain an understanding of how to work together in interdisciplinary teams. This would help them realize the significance of applying engineering knowledge to make a fully functional design and suggest recommendations for further improvement.

4.2 Demonstrate an ability to design and conduct experiments, as well as to analyze and interpret data

The TGR projects require extensive design and experimental analysis. For instance the deployment, placement, and orientation of RFID tags (used for localization of the robot) vary the reading range significantly. Incorrect orientation reduces the system reliability towards failure. Accordingly, students need careful experimentation through implementation and analyzing data. On the ME side of the project, with majority comprising of moving elements, students need to perform detailed stress, strain, loading, torque, and power transmission calculations.

With these projects requiring extensive experimentation and data analysis, students can be taught how to design efficient experiments and analyze data through statistical analysis such as ANOVA, Taguchi, and Scheffes methods. Reinforcing this statistical analysis further helps them understand the utility of experimental design within an engineering context.

4.3 Demonstrate an ability to function on multidisciplinary teams

In this "flat-world"[3], engineers need to constantly absorb and teach others new ways of doing old or new things, and mostly learn how to work well with others. The TGR project requires collaboration of students from multiple disciplines. Through these projects and by working with others, students obtain opportunities to experience a different domain; combine knowledge and skills from different disciplines; work as a team member; and solve real-time research problems. Also, this interdisciplinary collaboration provides students with significant personal development opportunities[4].

4.4 Demonstrate an ability to identify, formulate, and solve engineering problems

Each student team working on TGR platform will be assigned a design project to undertake an engineering problem. The whole process exemplified the students' ability to identify, formulate, and solve engineering problems. This requires students to plan the design process of project definition and planning, specification definition, concept development, detail design, testing and refinement, and production.

4.5 Demonstrate an understanding of professional and ethical responsibility

The TGR design platform is a natural place to introduce ethical as well as global engineering issues. By working on these projects, students obtain first hand feedback from the end user. This helps students obtain a clear picture of the health and wealth of public, and to disclose promptly the factors that might endanger the end user. By working with end user, but not the corporate industries, students have the ability to approach system design based on usability rather than monetary profits, realizing the ethical responsibility of engineers. Largely, TGR platform helps students use their knowledge and skills for the enhancement of human welfare, and motivates them to strive for increasing the competence and prestige of engineering profession.

4.6 Demonstrate knowledge of contemporary issues

Knowledge of contemporary issues such as economical, environmental, social, and ethical factors are crucial in the design process of any engineering system. Engineering students prior to graduation must be able to identify these factors and make appropriate judgments in any project they undertake. The TGR platform in capstone senior design is ideal to educate the students in this process. For instance, consider a project designed to assist a blind person navigate inside a building. Two primary challenges faced by a blind person are mobility and orientation. The inability and fear of conquering such overwhelming challenges often prevent them from leading productive and socially active lives. Students can relate how technological advancement such as RFID and GPS can be used for navigational cues, and ultrasonic sensors for obstacle avoidance, answering the challenges of mobility and orientation. In essence, TGR serves as an excellent platform for students to enhance their knowledge and understanding of contemporary issues in the engineering design process.

5. Conclusion

This paper described a tour guide robot based platform for capstone senior design projects. With majority of the concepts required for this projects already taught in existing core engineering classes, this platform can fit into any engineering curriculum to educate students in the cutting edge technology, while at the same time show how they could make an impact in the community. Upon initial implementation at the host institution, students have reported a high degree of satisfaction and were able to publish their work in technical conference. There were a number of other gains from this platform including obtaining equipment donations from the university, industry partners, and obtaining internship positions for students in the local industry. With the RFID technology progressing from an emerging technology to essential commodity, the tour guide robot platform can be adapted for success in any institution offering engineering and technology degree programs.

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