Tour Guide Robots: An Integrated Research and Design Platform to Prepare Engineering and Technology Students

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Abstract

Many interesting research and design questions occur at the intersections of traditional disciplines, yet most coursework and research programs for undergraduate engineering students are focused on one discipline. This leads to underutilization of the potential in better preparing students through multidisciplinary projects. Identifying this opportunity to better prepare the engineering and technology students, this paper presents a multidisciplinary integrated research and design platform on tour guide robots. Through integration of electrical hardware, mechanical systems, design manufacture, and complex programming, the proposed work serves as an ideal platform through which students will be able to study a complex and integrated engineering system. Preliminary implementation of the proposed platform has led to numerous undergraduate research projects, capstone senior design projects, course improvements, publications in peer-reviewed conferences, and best student paper awards.

1. Introduction

Rapid advancement in technology has laid a path for the design and manufacture of many multidisciplinary integrated technologies. However, 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 integrated and multidisciplinary research and/or design projects. Over the past few years, the diversity and number of research experience projects for undergraduate students have increased significantly. A well designed research or design project has the potential not only to expose participants to exciting scientific advancements, but also serves as a catalyst for the career development of faculty members in an undergraduate degree offering institution. Literature review has shown that undergraduate students extensively indicate personal and intellectual developments [Hunter, 2007] as well as recognition by mentors [Hurtado, 2008] after participation in such research and/or design projects.

On the other hand, one key component of providing a broad education is the multidisciplinary experience gained by working on projects that are open-ended and complex and attempt to provide solutions to practical real-world problems [Dombach, 2007]. By working in such teams, students: i) obtain opportunities to experience a different domain; ii) combine knowledge and skills from different disciplines; iii) work as a team member; and iv) solve real-time problems. Also, this collaboration provides students with significant personality development opportunities [Skates, 2003], and the open-ended and complex projects attempt to provide a solution to a practical real-world problem. A majority of such problems require solutions that integrate sensing, computing, and implementing concepts from several disciplines [Gennert, 2012]. Within this context of multidisciplinary research or design projects, *tour guide robots* is an ideal field of study that can be used to sustain and broaden engineering education, promote team work, technical competency, innovation, lifelong learning, and also serve as a good recruitment tool for prospective engineering and technology students. This multidisciplinary nature of robotics makes it suitable for undergraduate students to broaden their experience before they enter the engineering workforce.

In fact, over the past few years, robotics has evolved to become a rather diverse field covering a wide spectrum of applications ranging from assistive technologies to consumer robotics products, from industrial to warfare applications, fixed to adaptable shape, large to micrometer scale robots. Infusing such a state-of-the-art technology in the undergraduate classroom plays a vital role in hands-on multidisciplinary activities and demonstration for students to learn the interconnection of Science, Technology, Engineering, and Mathematics (STEM) concepts. Encapsulation of these diverse concepts in a common platform provides opportunities for incorporating the same into undergraduate engineering not only in the form of coursework but also as research and design projects, from high level through subsystem requirements level. Overall, the multidisciplinary nature of *tour guide robots* (TGR) platform can cover multitude of engineering and technology disciplines with focus areas presented in figure 1.

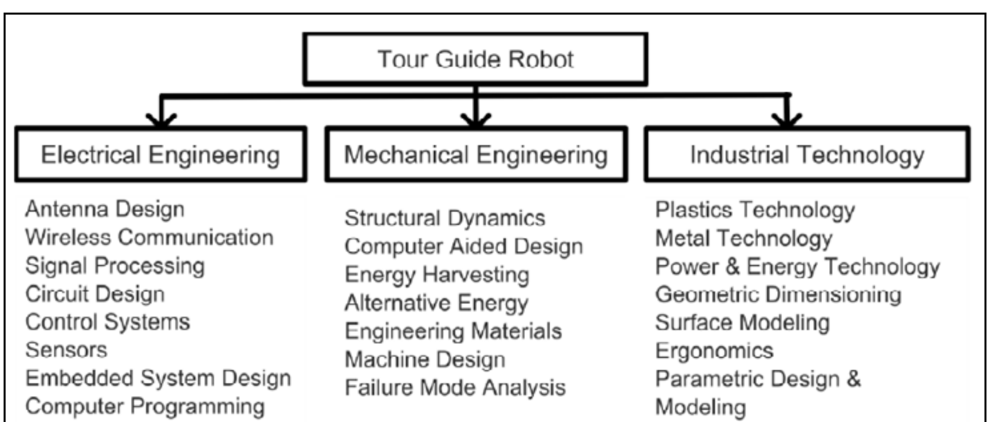

Figure 1: Potential technical focus areas covered in the TGR platform

2. Tour Guide Robot Platform

Numerous researches have presented various models of TGR's for diverse applications including but not limited to serving as a tour guide for an indoor museum, indoor manufacturing facilities, outdoor tour of a university campus, serving as a butler in a hotel, etc.,[Buckner, 2009; Crook, 2014; Pai, 2014] While the application of these robots are different, the fundamental sub-systems in the TGR architecture are the same and include i) robot navigation module; ii) obstacle detection system; iii) onboard signal processing; iv) motion control system; and v) input-output user interface as presented in the prototype of a TGR in figure 2.

2.1 Robot Navigation Module

Robot navigation is its ability to find a safe path to travel from start to destination while localizing itself in the environment using sensorial data. This robot navigation has been an open and challenging problem over the last few decades, and despite significant advances in the field, researchers have yet to reach a comfortable level of satisfaction [Gueaieb, 2008]. Mobile robots need a reliable localization method to move about and perform assigned tasks. In particular, during navigation, knowledge of location and position are highly important. One of the most well-known localization systems in outdoor environments is the global positioning system (GPS), a satellite based navigation system made up of a network of 24 satellites in orbit [Garmin, 2014]. As the GPS operates based on time of signal arrival from satellites in the orbit, poor satellite receptions in an indoor setting limits the applicability of a GPS while operating indoors. Identifying this challenge, numerous researchers have proposed indoor localization techniques including but not limited to active bat localization system based on ultrasonic sensors [Harter, 1999], 2D and 3D cameras for visual representation of the environment [Lu, 1997], and passive Radio Frequency Identification (RFID) based methods [Yelamarthi, 2014]. Once the location and position information of the robot is obtained, given a map and destination information, the robot navigation path indoors or outdoors could be calculated using one of the several methods in the literature [Gueaieb, 2008; Park, 2009].

2.2 Obstacle Detection System

A TGR while operating indoors or outdoors has to constantly move around obstacles to accomplish its set task. As these obstacles might be static or dynamic in their position, the obstacle detection system must continually identify the obstacles position, in order to evaluate its continuously changing trajectory in the environment. A broad range of obstacle detection systems are available in the literature and differ by the complexity of navigation environment, ability to identify size and shape of obstacles, and accuracy. For an application where detecting an obstacle within a distance of 30cms directly in front of the robot would suffice, a simple infrared (IR) sensor could be used, where as if a broader obstacle detection range is required, a more advanced systems such as ultrasonic sensor or laser system could be used as they can provide a near 360º range of detection across the TGR.

Figure 2: Prototype of a tour guide robot

2.3 Input-Output User Interface

An input-output user interface is the primary module that enables communication between prospective user and TGR. The input module allows a user to instruct the robot to perform an action such as providing a tour of the facility or navigation assistance to reach a specific destination. A broad range of methods to capture user input have been presented in the literature, and include a numeric keypad, speech recognition systems, and touch interfaces where the user can select one of the many preprogrammed actions [Adkins, 2011; Beckwith, 2012; Olszewski, 2013; Yelamarthi, 2010]. The output module serves as a mechanism through which feedback or relevant information is provided to the user. Based on the information presented, the output module can be designed using a series of LEDs, simple LCD screen to display text, speaker to play a preprogrammed audio tracks, or a small computer monitor to play presentations and/or videos. It is to be noted that a touch screen monitor could serve as the input-output user interface modules to acquire user input and also provide feedback or further information.

2.4 Onboard Signal Processing

The diverse range of sensors such GPS, RFID for localization, IR, ultrasonic, and laser for obstacle detection, actuators to move the onboard components, and user interface devices necessitate the presence of an onboard signal processing system on the TGR. Similar to other subsystems in the TGR, range of onboard signal processing unit can vary based on the complexity of tasks to be performed. For a simple operation such as navigating a simple robot through a predefined route, a combination of simple microcontroller and few circuit elements could be used. For an advanced TGR that requires capturing the user information such as their respective profiles, selection of task to be performed, and providing feedback through presentations and videos, it is optimal to use a portable computer.

Overall, the proposed TGR platform is ideal for undergraduate engineering and technology programs as it: i) allows for the formulation of several discipline specific or multidisciplinary projects; ii) showcases how the skills gained in the engineering and technology curriculum could be used to present a solution for a real-world problem; iii) helps prospective engineers gain a deeper understanding of engineering and technology context through an integrated and collaborative environment. Labs and projects resulting from this integrated platform could be integrated into the existing engineering and technology curriculum towards course improvements as presented in Table 1.

3. TGR Based Research Projects

3.1 RFID based indoor localization

Recent technological advancements in wireless communication systems, sensors, and hardware have made it possible to implement solutions that were once thought to be impractical. One such technology is RFID that relies on remotely storing and retrieving data using tags and readers. The convergence of this RFID and other wireless technologies lies at the heart of many novel applications such as remote medicine, intelligent transportation system, access control, wireless remote sensing, remote warehouse management, early warning systems, and locating points of interest [Chawla, 2011]. Besides identifying the existence of an object within the detection range, accurate location information of the object is vital for many applications. While identifying location of objects not only promotes context awareness at the application level, it also impacts low-level functionalities such as routing, service discovery, and resource management. This process of localization often acts a bridge between the virtual and physical world [Estrin, 2002], and is used to find the spatial relationship between objects.

With the primary objective of RFID being object identification, the usage of RFID technology has seen a significant growth. However, a recent major study has shown that the probability for success in RFID based object identification can be as low as 66%. Some of the several challenges in object identification are tag orientation, placement location, environmental factors such as radio and ambient noise, interference, ambient factors such as water and/or metal etc. Simultaneously, a few of the contemporary issues students dealt with during the project include usage of radio frequency waves in an indoor environment and the potential impact on the users, potential opposition for the electric vehicles due to its quietness from blind people, increasing demand for energy sources, further complicating the process of charging robots during work hours. Identifying this challenge of object identification and localization, this project entails the design and implement a unified RFID based indoor positioning system as presented in figure 3, and has been completed as a two semester capstone design project in the 2012-12 academic year [Olszewski, 2013].

3.2 A Highly Accurate Indoor Navigation System

Indoor positioning systems (IPS) locate objects in closed structured such as warehouses, hospitals, libraries, and office building, where GPS typically does not work due to poor satellite reception. Inherently, indoor positioning is a vital challenge facing the industry for a long time. Most of the available IPS operate based on optical tracking, motor encoding, and active RFID tags, often limited in their accuracy or high hardware cost. Answering this challenge, this project could present a passive RFID and wireless sensor networks based localization system for indoor positioning using a mobile robot.

Utilizing passive RFID tags places in a uniform

Course (Discipline)	Course Objectives	Potential Improvements
Introduction to Engineering (CE, EE, ME, IET)	i) describe the engineering profession and its various disciplines; ii) apply the basic problem solving skills of engineering; iii) work in teams; iv) apply the engineering design process to a broad variety of design projects	First-year students can gain hands-on exposure to real-time designs. Through this exposure, instrumentation and data analysis, and multidisciplinary team work, students will be prepared to step forward into research projects early in their education.
Digital Circuits (CE, EE, ME)	i) perform arithmetic operations using binary, octal, and hexadecimal numbers; ii) describe the operation of logic gates; iii) perform gate level minimization algebraically and with advanced methods; iv) design and improve simple synchronous sequential logic circuits; v) implement digital circuits utilizing electrical laboratory procedures; vi) understand the basics of computers, sensors, and actuators and the relationships between them in a robotics context.	The diverse nature of data acquisition sensors such as IR and ultrasonic for obstacle detection, GPS and RFID for localization, and microcontrollers could be used to introduce digital electronics and their respective real-time applications. The hands-on design activities will demonstrate how to implement simple digital circuits using electrical laboratory procedures, and the underlying relationships between sensors and actuators in a robotics context.
Metal/Plastics Technology	i) apply a working knowledge set of basic manufacturing processes in machining, sheet metal, casting, and welding operations; ii) develop the ability to use basic measurement tools; iii) apply methods used to produce products in a timely fashion; iv) demonstrate safe work habits utilizing machines and tools; v) recognize how blueprints and process sheets are used to produce products.	Through analyzing TGR prototypes, students gain understanding of manufacturing process in machining and casting, while learning about CAD drawings, blueprints, process sheets, and methods used to produce products in a timely fashion. This will provide students a broader perspective of concept implementation in technology devices.
Circuit Analysis I (CE, EE, ME)	i) find power and current as functions of time; ii) apply basic rules and laws to analyze circuits; iii) perform mesh and nodal dc circuit analysis; iv) calculate voltage, current, power, and energy in a single and combined capacitors or inductors; v) determine power factor, maximum real power transfer.	The real-time projects from the TGR comprises of several circuit modules including but not limited to power bus, driver electronics for motors, noise cancellation circuits, input-output expander elements., They could be used to demonstrate the basic rules and laws to design and analyze dc circuits, perform power calculations, etc.
Machine Design (ME, IET)	i) design common machine elements using linkages, cams and gear trains; ii) carry out positional analysis of mechanisms; iii) carry out velocity analysis of mechanisms; iv) carry out acceleration analysis of mechanisms; v) determine dynamic forces in machines.	By performing extensive data collection and analysis, students learn the limitations and strategies in machine design. This further increases knowledge base and demonstrates critical design principles behind machine design.
Embedded System Design (CE, EE)	i) Describe architecture of 68HC12 microcontroller; ii) Design interface hardware to connect microcontroller to different types of I/O devices; iii) Program microcontroller using interrupt synchronization in multithreaded environment; iv) Design systems for real-time applications such as real-time signal processing and real-time control.	TGR projects can be used to demonstrate efficient strategies in designing a system to meet desired needs within realistic constraints such as economic, social, ethical, manufacturability, and sustainability. These methods teach students the effective strategies for designing embedded systems while cultivating ethical standards in the process.

Table 1: Potential curriculum improvements through the integrated TGR platform

triangular fashion for low tag density, a fusion of methods such as time difference of arrival and received signal strength could be used to help a robot navigate with high accuracy. Simultaneously, a few contemporary issues students dealt with during the project include high usage of energy, inherent requirement to generate more electricity to meet this need, reduced dependency on human workforce and its potential impact on labor etc. Initiated as a two semester capstone design project in 2013-14 academic year at the host institution, the system was later refined for high accuracy as a research project [Yelamarthi, 2014]. The presented IPS first estimates its location using a centroid method, and utilizes time difference of arrival from wireless sensors to accurately estimate its position, and uses trigonometric identities to estimate its current orientation. Experimental results demonstrated that presented IPS can effectively perform indoor positioning and navigate to its destination with an average accuracy of 0.07m, while avoiding any obstacles in the path.

Figure 3. Prototype of an RFID based indoor positioning system

applications, one prevailing challenge is mobile robots navigation in presence of dense obstacles. Identifying this challenge, this research project presents an efficient and dynamic algorithm for accurate mobile robot navigation through a portable integrated system equipped with a Pioneer P3-DX robot [Pioneer, 2014; Yuan 2014] with an array of sonar sensors. Based on the input received from the user, the presented algorithm can dynamically calculate the most efficient route to reach the destination, and travel the route by avoiding any obstacle in its path. Through implementation and extensive testing, the presented algorithm was able to detect obstacles with 98% accuracy, and reach its target location with an average position error of 0.009m, and was completed as an undergraduate research project in the 2013-14 academic year at the host institution.

3.4 Trajectory planning for a Robot using

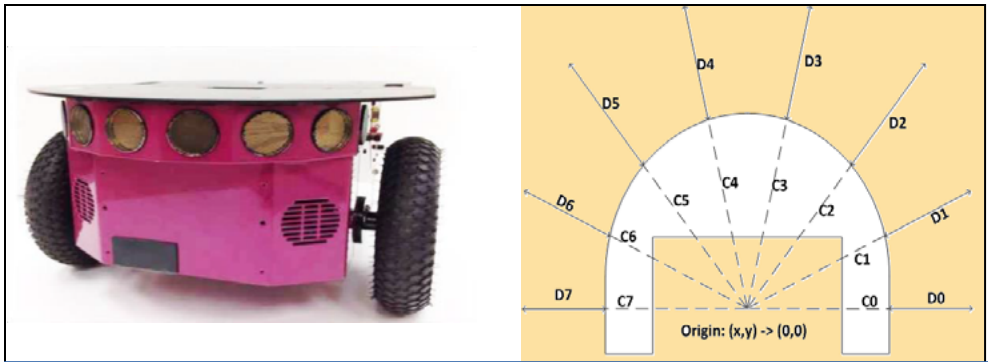

Figure 4. Protoype of sonar based mobile robot navigation system and placement of sensors on robot

Depth Sensors

Path planning and controlling mobile robots has garnered attention during the last two decades. The classical navigation problem consists of finding a control strategy in order to move a robot from start to destination without hitting any obstacles in the path. This obstacle detection is typically done using an array of sensors which are often either limited in their detection range, or quite expensive. A depth sensor such as Microsoft Kinect or Asus Xtion Pro is an inclusive sensor that comprises of a typical camera to identify the field of view, and a depth sensor that can generate a distance map for every point in the field of view. In this project, the depth sensor can be used to abstract the environment in the field of view, perform cell decomposition to categorize the environment between physical stationary objects, dynamically moving humans, and open space to plan and navigate a trajectory from current location to destination. Furthermore, this method of cell decomposition and environment categorization might be used not just in the tour guide robot, but could be adapted in other applications such as warehouse management robots. Simultaneously, a few of the contemporary issues students dealt with during the project include high dependency on robotic systems and its potential negative impact on human work force, increased number of jobs created in interdisciplinary areas of engineering to create such robotic systems, increased dependency on energy sources etc. This project is currently a work in progress at the host institution and results obtained will be published soon.

4. ABET Criterion

One of the primary factors considered during curriculum design is following ABET guidelines to ascertain that curriculum meets the ABET Criterion 3 requirements of addressing the skills, knowledge, and behaviors students should have at the time of graduation [Engineering Accreditation Commission, 2014]. This section briefly outlines how the proposed platform meets this ABET criterion.

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

The multidisciplinary and collaborative nature of projects in the proposed platform serve as an ideal method to nurture student knowledge in mathematics, science, and engineering through design and implementation. Particularly, EE student can further their skills in programming embedded systems, circuit design, and signal processing concepts including but not limited to interference and shielding, multiplexing, polarization, resonance, crosstalk, and multipath fading. The ME students can further their skills in kinetics, concurrent forces, moments of inertia, force calculation, stress and strain, loading and deformation, and kinematics.

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

The projects in the proposed platform require extensive design and experimental analysis. For example, deployment, placement, and orientation of RFID tags, GPS sensor, or dynamic location of robot vary the reliability of operation, and thus requires extensive experimentation. Also, physical size and continuous motion of the robot requires detailed stress, strain, loading, torque, and power transmission calculation, often leading to extensive design of experiments, implementation and data interpretation to ascertain reliable and safe operation.

Through this integrated platform, students can learn how to design experiments with statistical procedures such as factorials, randomization, and analyze data through statistical methods such as t-test, analysis of variance, Taguchi, levene statistic, and scheffes methods. This design of experiments educates students in the fundamental and systematic procedures followed in the product development cycle of any real-time engineering system [Ulrich, 2011].

4.3 Demonstrate an ability to function on multidisciplinary teams

In this "flat-world", 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 [Friedman, 2005]. Projects in the proposed integrated platform 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, collaborate in teams, and solve real-time research problems. Also, this multidisciplinary collaboration provides students with significant personal development opportunities [Skates, 2003].

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

Each student team working on a project in the proposed integrated platform could be assigned a design project to undertake a discipline specific engineering problem, which could be later used to solve a larger multidisciplinary engineering problem. This method exemplifies students' ability to identify, formulate, and solve engineering problems. Further, it 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 proposed integrated 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, students have the ability to approach system design based on usability rather than monetary profits, realizing the ethical responsibility of engineers. Largely, proposed platform helps students utilize 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 economic, 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 proposed integrated platform in capstone senior design is ideal to educate the students in this process. For instance, in 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, and propose a solution for mobility and orientation. In essence, proposed integrated platforms serves as an excellent manner through which students can enhance their knowledge and understanding of contemporary issues in the engineering design process.

5. Conclusion

This paper presented an integrated research and design platform based on tour guide robots to better prepare the engineering and technology students. With majority of necessary technical concepts for the presented projects being taught in existing core engineering and technology curriculum, the proposed integrated platform can be adapted for curriculum to better prepare the students in cutting edge technology, while at the same time nurture their interest in engineering and technology through real-world problems. Upon initial implementation at the host institution, numerous students have worked on several TGR based projects, published and presented their findings at peer-reviewed conference, won best student paper awards, secured internship and full time positions upon graduation, and reported a high degree of satisfaction [Adkins, 2011; Beckwith, 2012; Ghelichi, 2013; Laubhan, 2014; Olszewski, 2013; Yelamarthi, 2010; Yelamarthi, 2012].

There were a number of other gains from this platform including obtaining equipment donations from industry partners, and development of instructional resources for incorporation into the existing engineering curriculum. With the RFID technology progressing from an emerging technology to essential commodity, the projects presented can be adapted for success in any institution offering engineering and technology degree programs. Overall, the proposed integrated research and design platform has been effective in: i) focusing on undergraduate student academic excellence and preparing them to begin engineering and technology careers as inventors and researchers; ii) emphasizing both competence and contribution of multidisciplinary designs in the engineering and technology community at large; iii) enhancing the students ability to participate in a collaborative and diverse setting; iv) designing new instructional resources (labs/design projects) for incorporation into engineering and technology curriculum; and v) engaging students in cutting-edge technologies relevant to real-world applications.

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