CATE: An Autonomous Indoor Tour Guide Robot

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Abstract —This paper describes a radio frequency identification (RFID) and sonar-guided tour guide robot, CATE (Central’s Automated Tour Experience). The portable terminal unit is an embedded system equipped with an RFID reader for localization, and sonar and IR sensors for obstacle detection and avoidance. CATE can guide the visitor through a predefined tour of the building, or create a new route on-the-fly. While in predefined tour mode, CATE completes the tour by avoiding obstacles using sonar and infrared sensor input. It will also provide audio and video information through an onboard computer, and can collect feedback from the user through a touch screen display. CATE has been successfully implemented and is under final stages of testing.

I. INTRODUCTION

With the increase in demand for higher education, prospective students and their parents are becoming attentive while choosing a college for higher education. While attending a campus tour guided by an individual is a great method for learning about the university, and its points of merit, many a times these campus tour guides fail to provide the information sought by these prospective students. Due to the limited time available during tours, tour guides often focus on conveying their personal experiences, and share common knowledge about a few program. Although this guided tour is an effective to certain extent, other innovative methods are necessary to spark student interest towards any specific program. The Central’s Automated Tour Experience (CATE) is one such method, where a tour guide robot is used to provide prospective students a tour of the engineering facility, inform them about programs available, and spark their interest in engineering and technology programs at the host institution.

Over the past few years, several methods have been proposed in the areas of tour guide robots. Rhino [1] operated by employing sonar and infrared sensors, laser range finders, and touch sensitive panels to navigate its environment. It required the programmer to upload the environment map prior to operation, and used a modified version of Markov localization. However, it operates under the assumption that the environment is static, thereby requiring complex probabilistic algorithms to prevent localization failure. Minerva [2,3] greatly improved on Rhino’s design by gaining the ability to learn about its environment using ceiling mosaics, and added a robotic face to convey emotional states for engaging people. However, with is limited speech recognition capability, it could not truly interact with its visitors. Virgil [4,5] developed at Rice University used odometer readings to navigate around campus, and GPS for course correction. However, it has limited capabilities in navigating around obstacles, and also lacks the ability to interact with its visitors.

Jinny [6] used two laser finders and two infrared sensors for navigation, and a Monte Carlo based probabilistic map-matching scheme for localization. While it has advanced human robot interface system, it suffers from localization problems and its requirement to remotely correct the system from navigational errors. The Bryn Mawr robot [7] utilized sonar sensors for navigation and cameras for localization. While each of these tour guide robots serve the basic purpose, all of them suffer from many limitations. Rhino for example is not capable of learning about its environment on the fly, Virgil cannot detect obstacles unless it comes in contact with them, and primarily every robot benchmarked requires a clear line of sight for localization.

Answering some of the stated challenges, this paper presents the research, design, and implementation of an autonomous radio frequency identification (RFID) and sonar guided tour guide robot, CATE as shown in Fig. 1. It will guide visitors through the engineering building, provide them with detailed, up-to-date information pertinent to the various programs offered, and the diverse research and design opportunities available for students. In addition, it will showcase student work, and serve as a platform for undergraduate student research and design projects.

Fig 1: Design Rendering of CATE
II. DESIGN IMPLEMENTATION

A. Mechanical Stability

CATE’s chassis as presented in Fig. 1 was based around a Pioneer 3-DX [8] base produced by Adept Mobile Robots. It utilizes some of the systems incorporated into the P3-DX. Most importantly, the P3-DX provided sonar sensors, two differential motors, and a serial port that are integrated into a built-in microcontroller. The two Ametek Pittman differential drive motors provide a torque of 0.023Nm/A per eq. (1) allowing CATE to reach a top speed 1.6 m/s with a payload of 50 lbs [8]. The two drive wheel and one castor wheel layout of the P3-DX offers a significant advantage over other options with its higher stability, ease of control, and lower power consumption. With all the additional body and components attached, CATE’s center of mass was calculated using eq (1).

\[ y_c = \frac{\sum m_i y_i}{\sum m_i} \quad (1) \]

where, \( y_c \) is the location of the center of mass from the ground, \( m_i \) is the mass of each component and \( y_i \) is the location of center of each component. Based on the weights and positions of all the parts, center of mass for CATE was found to be located at an acceptable height of 0.416m from the ground, which is less than half of the CATE’s 1m height. With CATE having to move on different surfaces (tile, carpet, concrete etc.), stability is crucial for safety reasons. Accordingly, no slipping was assumed and sum of moments as in eq (2) was applied to compute the stability.

\[ \Sigma M_a = 0 = F_c y_c - F_t y_t \quad (2) \]

where, \( M_a \) is the moment about the point of contact between CATE’s wheel and ground, \( F_c \) is the force caused by CATE’s mass, \( F_t \) is as applied force at the top of CATE, and \( y_t \) is the total height of CATE. By accounting for all the components and parts located on CATE, eq (2) has demonstrated that a force of at least 98N is required to disrupt CATE from equilibrium. Preliminary testing has shown that stability is not a problem in CATE.

Additionally, the tall frame (1m) of CATE allowed for incorporating more sensors, a display, and other mechanical components. One such component was a linear actuator that raises the display during tours for easier viewing. Contrarily, when retracted the linear actuator allows the display’s position to be at a comfortable height and angle for optimum use of the displays touch screen as shown in Fig. 1.

B. Embedded System

The embedded system of CATE has been classified into input module and output module as shown in Fig. 2. The input module comprises of user input device, obstacle detection sensors, and localization devices. The output module comprises of user video and audio modules, wheel motors, and audio feedback device. Both these modules were interfaced using an embedded microcontroller and a notebook computer (PC) that serves as brain of the system, and also for providing information to tour attendees. Localization is performed using a SkyeTek DKM9 RFID system [9], and obstacle avoidance navigation is performed using sonar arrays and two Sharp GP2D12 infrared (IR) sensors [10]. The speaker system along with on board PC will be used to provide tour information to the respective users. In addition, the touch screen display of this PC also serves to obtain feedback from the user. The RFID patch antenna is mounted outside the CATE chassis, and all other hardware is enclosed inside as in Fig. 1.

Fig 2: CATE’s Embedded System with Input and Output Modules
As all the components of CATE require different voltage levels, ranging from 3.3 to 12 volts, a power bus has been designed. The IR sensors operate on 5 volts, and RFID operates at 6 volts. As the ultra high frequency RFID system consumes a relatively large amount of current, an independent voltage regulator and fuse have been used. Polymeric temperature coefficient resettable fuses have been used throughout to prevent design failure. A switch in the power bus will allow the user to turn the CATE on and off in case of any electrical problems. All the components of CATE have a combined maximum current of 3A. However, rarely will the device require maximum power. Based on this assumption and heuristic analysis, CATE uses 6600 mAh 14.8 V Lithium ion battery sufficient to allow the users to provide tours for at least three hours on a single charge.

The touch screen display of the onboard PC serves to start the tour presentation. Once the start button is pressed, the PC sends appropriate commands to SH2 microcontroller through a dedicated USB to initiate the tour. At the same time, the RFID system communicates with the PC through a different port for CATE’s localization. When the RFID system determines that CATE is present at a point of interest, it will send a signal to the onboard PC. Accordingly, the PC will retrieve a MS Power Point presentation and run it to inform the visitors about the respective point of interest. The sonar and IR sensors are integrated to the input ports of SH2 microcontroller, which constantly monitors these ports, and sends appropriate signals to the onboard PC. These signals are then analyzed to detect presence of any obstacle, and initiate the obstacle avoidance routine accordingly.

III. LOCALIZATION AND OBSTACLE AVOIDANCE

A Skyetek DKM9 RFID development kit operating at 915 MHz has been used for localization of CATE. Through extensive testing it was found that this development kit in combination with a patch antenna has a read range of approximately 1m. Accordingly, RFID tags will be placed on the walls of indoor hallways, and CATE will move in the hallway with a distance of <1m from the walls through out the tour. In order to differentiate between points of interest, each tag is encoded with 24 bytes of information. The first 22 bytes are common among all tags to ensure that correct tags are read, and prevent unwanted tags disrupting CATE operation. The last two bytes allows to code 32 unique tags, sufficient to flag 17 points of interest in the building. If the number of points of interest in the tour increases, some of the 22 bytes could be used to differentiate between them.

The 17 points of interest in the Engineering and Technology building are tagged with RFID tags, and encoded with numbers one through seventeen. When the CATE reads an RFID tag, it retrieves appropriate information and presents it on the display screen for the visitors. Once each point of interest is visited, its information is stored in the program, to assess if CATE is moving in the correct path without missing any points of interest. Additionally, a condition will be programmed such that if CATE moves 15m without reading an RFID tag, it will send a signal to the control room for remotely navigating the system to a safe location.

CATE comprises of a sonar array with 8 sonar sensors integrated into the SH2 microcontroller. Located at 90°, 50°, 30°, 10°, -10°, -30°, -50°, and -90° along the front side, each sensor has an aperture of 15° as shown in Fig. 3. When activated, the SH2 continuously reads information from these 8 sensors, detects any obstacle present, and computes its location and distance from CATE. If the object detected is found to be stationary and within a distance of 1m, CATE will turn left by 90° and evaluate the area immediately in front. Once the path is clear, it will move forward until it passes the obstacle (detected by side sonar sensor), turn right by 90°, while at the same time keep track of the distance ‘x’ it travelled. Then it travels forward until is passes the obstacle (detected by side sonar sensor), keeps tracks of distance ‘y’ travelled, and turns right by 90°. Once it passes the obstacle, it travels back by distance ‘x’, turns left by 90° and continues the tour as shown in Fig. 4.

![Fig 3: Placement of sonar array on the front side of CATE](image)

![Fig 4: CATE’s Stationary Obstacle Avoidance Routine](image)
On the other hand, if the obstacle detected is found to be moving, CATE will wait for the obstacle to move from its tour path. If the obstacles do not move even after a certain amount of time, it will send a signal to the control room for the operator to remotely navigate CATE around the obstacle. In the event that CATE misses a point of interest during obstacle avoidance routine, it will announce the same to the visitors, present the information, and continue with the tour.

Fig 5: Operational flow chart for CATE
IV. CATE SYSTEM OPERATION

The localization, navigation, and operational algorithms for CATE are shown in Fig. 5. Operation of CATE starts when a tour attendee or provider presses the “Start Tour” icon on the display screen of on-board computer. At this time, CATE will active the linear actuator, lift the screen to eye level, and start a MS Power Point presentation to welcome everyone, and inform them about the different programs and facilities available in the host school. Upon completion, it will initiate the navigation and presentation program.

First, using information from side IR sensors, CATE will find if it is within a distance of <1m from the wall to ascertain reading RFID tags accurately. If IR sensors indicate that CATE is too far from the wall, CATE will initiate the “Wall Correction Subroutine” and correct its position to be within that 1m range. Once CATE has positioned itself correctly with respect to the wall, it will start moving forward while looking for obstacles in its path. If the sonar array or IR sensors detect any obstacle, CATE will initiate the “Obstacle Avoidance Subroutine,” and navigate around it as explained in section III.

While moving forward it keeps tracks of distance ‘d’ travelled, and the RFID reader will continuously look for RFID tags preloaded with information on points of interest. When an RFID tag is detected, it will initiate the “RFID Subroutine.” This subroutine will compare information on the tag detected with the database, to find if the tag refers to a specific point of interest, it will reset distance ‘d’ to zero, load appropriate information on the onboard computer screen, and inform the attendee accordingly. On the other hand, if it finds that tag detected refers to ‘End of tour,’ CATE will reset distance ‘d’ to zero, turn 180°, and return to the starting point.

While moving forward, when distance ‘d’ increases to 15 m before it reads a point of interest RFID tag, CATE interprets this is incorrect path movement, and send a signal to the control room for remotely controlled navigation to starting point. As long as d<15m, CATE will move forward in the tour until it reads the ‘End of tour’ tag. At this point, CATE will turn 180°, and return to the starting point.

V. PRELIMINARY TESTING

CATE is a work-in-progress and has yet to be tested extensively. To test system’s ability in addressing project requirements, the design team has created appropriate experiments to quantitatively and qualitatively assess CATE’s performance under a controlled environment. Data was collected and analyzed to validate its reliable implementation. Pilot experiments focused on testing each sub-system (obstacle detection, avoidance, localization, and communication between each). The RFID localization system was tested for optimal orientation, angle, and placement of tags. Accordingly, it was found that the onboard RFID system could read multiple tags efficiently within a distance of 1m. Accordingly, the wall distance correction subroutine was programmed to maintain CATE within 1m of distance from the wall.

The sonar and IR sensors have been extensively tested as well. It was found that sonar sensors could efficiently find the location and distance of the obstacles in a radius of 0.1-5.0 m. Accordingly, the obstacle avoidance subroutine was programmed to efficiently navigate CATE around obstacles. Another function of CATE’s operation that has been tested extensively is the communication among sub-systems (onboard computer, SH2 microcontroller, and the P3-DX base). After extensive programming and testing, a successful communication protocol has been established for a smooth and reliable operation. Research is currently in progress to localize RFID tag within an accuracy of 0.3 m, and interfacing the linear actuator to onboard computer.

VI. CONCLUSION

The concept of utilizing RFID for localization of objects has been shown to be both technically and economically feasible. The tour guide robot, CATE was successfully designed and implemented to provide group tours for prospective students visiting the university campus. In the near future, we plan to improve the localization and navigation algorithm for CATE to navigate through more dynamic environments with obstacles. Further analysis will be performed to accurately identify CATE location by placing RFID transponders at different patterns and distances.

REFERENCES