RFID and GPS Integrated Navigation System for the Visually Impaired

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Abstract—This paper describes an RFID and GPS integrated navigation system, Smart-Robot (SR) for the visually impaired. The SR uses RFID and GPS based localization while operating indoor and outdoor respectively. The portable terminal unit is an embedded system equipped with an RFID reader, GPS, and analog compass as input devices to obtain location and orientation. The SR can guide the user to a predefined destination, or create a new route on-the-fly for later use. While in navigation mode, the SR reaches the destination by avoiding obstacles using ultrasonic and infrared sensor inputs. The SR also provides user feedback through a speaker, and vibrating motors on the glove. The SR prototype has been successfully implemented and is operational.

I. INTRODUCTION

The National Center for Health Statistics states that approximately 1.3 million people in the United States are visually impaired [1]. The following specifics put the visually impaired person dilemma into perspective and the challenges faced in the United States [2] alone: (1) Number of working age blind who are unemployed: 74% [3]; (2) Estimated annual cost of blindness to the US government: $4 billion [4]; (3) Lifetime cost of support and unpaid taxes for one blind person: $916,000 [5].

Given the persistence of gaps, it is not surprising that engineers can help the visually impaired person in their daily activities such as commuting. A visually impaired person in most cases uses a white cane to navigate and find the way. This traditional method is passive in that they must find their way using marking. If they fail to find the appropriate marking, they may face some problems. Also, in situations where this person has sensory organ problems or in emergencies, this is not a reliable method. An active navigation method with appropriate feedback to the user may be helpful for the visually impaired. Some visually impaired people use guide dog as an alternative. However, the dog must be trained for at least two years and the cost of training $38,000 is too high for many [6]. The American Foundation for the Blind states that over half of the legally blind people in the United States are unemployed, relying on their families for financial assistance [1]. Many families cannot afford the additional cost of a guide dog. Even after training and implementation costs, a guide dog can provide only limited assistance.

Navigation in unfamiliar spaces is a problem for the visually impaired [7], but learning is relatively rapid. So applications that support navigation in unfamiliar places are very helpful for the visually impaired [8]. Integration of current technology such as position recognition, obstacle detection, and embedded systems accommodates the design of a navigation system to help the visually impaired navigate easily.

This paper presents the design and implementation of a Radio Frequency Identification (RFID) and Global Positioning System (GPS) integrated navigation system; Smart-Robot (SR) to operate in both familiar and new environments. This navigation system helps the visually impaired people solve many problems such as, leaving home by themselves in a safe and convenient way, participate in more social and civic activities to improve their quality of life. At the same time, the reliable aid system for the visually impaired represents a civilized, harmonious, progressive society, and a service-oriented project for the engineers [9].

II. PREVIOUS WORK

Over the past three decades, research has been conducted to design new navigation devices for the visually impaired. Benjamin et al. [10] built a laser cane that uses optical triangulation with three laser diodes. The first laser points at the ground detecting a drop in elevation, the second points straight in front of the user parallel to the ground, and the third points straight ahead at an angle of 45° from the ground to protect the user from overhanging obstacles. Bissit and Heyes [11] developed a hand-held sonar device that gives the user auditory feedback with eight discrete levels. Shoval et. al [12] developed the Belt, an obstacle avoidance wearable computer for indoor navigation. Na [13] proposed an interactive guide system for indoor positioning, and Farrah [14] proposed the virtual reality technology to capture images of the house using cameras, and uses this information for indoors navigation. Kulyukin [15] proposed a closely related work, the robot-assisted navigation method for indoor environments.
While these devices have shown promise, they have several limitations. The laser cane provides no navigational assistance; a tone is triggered to indicate a drop off even for a small change in ground level (example: puddle); difference in the cane orientation with respect of the ground changes the direction of the lasers causing false audio cues etc. The handheld sonar device does not provide navigation assistance, and cannot detect drop-offs such as curbs, steps etc. The interactive guide system proposed by Na [13] works only indoors and does not detect obstacles in the travel path. The virtual reality technology proposed by Farrah [14] requires extensive image processing capabilities, and does not work in new or busy outdoor environments. The robot-assisted navigation by Kulyukin et al. [15] is closely related to our work, but has limitations such as: works only in structured indoor environments, and uses expensive lasers to classify the environment into cells of free space for navigation.

Also, many of these existing systems increase the user’s navigation-related physical load, as they require the user to wear additional body gear [12], contributing to physical fatigue. Based on the principles of universal design [16], the navigation systems for the blind should encompass design characteristics such as: equitable use, flexibility, simple and intuitive, perceptible information, tolerance for error, low physical efforts, size and space for approach and use, and acceptable process. In accordance with these guidelines, this paper presents the Smart-Robot, a RFID and GPS integrated navigation system for the visually impaired.

III. SMART-ROBOT DESIGN IMPLEMENTATION

The Smart-Robot is classified into input module and output module as shown in Fig 1. The input module comprises of user input device, obstacle detection sensors, and navigation and orientation unit. The output module comprises of user feedback devices, the SR motors for movement, display screen for troubleshooting, and a data storage unit. Both these modules are interfaced using a Motorola 68HCS12 microcontroller. Indoor navigation is performed using a SkyTeck DKM9 RFID system, and outdoor navigation is performed using a Garmin OEM 18x GPS. A simple 4x4 hex keypad is used to enter to the destination information. Obstacle detection is performed using two Sharp GP2D12 infrared (IR) sensors and one MaxSonar EZ0 ultrasonic sensor. Also, a Robson 1655 analog compass is used to keep track of SR’s movement during obstacle avoidance maneuvers.

The Smart-Robot entails two feedback signals, one from a small speaker, and the other from a glove with 10-mm shaftless vibration motors on the index, middle and ring fingers. These vibration motors are included to increase the reliability of feedback signals in noisy environment, and to accommodate for users with audio sensory impairment. The GPS antenna, RFID antenna, and the three obstacle detection sensors (ultrasonic and infrared) are mounted outside the chassis, and other hardware including the battery is enclosed inside the chassis as in Fig 2.

As all the components of SR require different voltage levels, ranging from 3.3 to 12 volts, a power bus has been designed as in Fig 3. The GPS, Ultrasonic sensors, IR sensors, and RFID operate at 5 volts. As the high frequency RFID system consumes a relatively large amount of current, an independent voltage regulator and fuse have been used. The DC motors, microcontroller and vibration motors all operate at 12, 9 and 3.3 volts respectively. Polymeric Temperature Coefficient (PTC) resettable fuses have been used throughout to prevent design failure. A switch in the power bus will allow the user to turn the SR on and off.

The components of SR have a combined maximum current consumption of 3A. However, rarely will the device require maximum power. Based on this assumption and heuristic analysis, the SR uses a 6600 mAh 14.8 V Lithium ion battery sufficient to allow the user commute for at least three hours on a single charge.

![Block Diagram of Smart-Robot](Image 110x82 to 516x314)

Figure 1: Block Diagram of Smart-Robot
With primary constraints of the SR design being simple and cost effective, off-the-shelf components have been used through the design. While operating outdoors, the GPS accuracy of \( \leq 2 \text{m} \) is high enough to keep the user on the sidewalk. When the user enters a building, the RFID system will activate to guide the user to appropriate destination. While indoors, the SR always moves close to the right wall for better RFID signal reception. Accordingly, the user can successfully use the SR to navigate safely both indoors and outdoors.

IV. SMART-ROBOT OPERATION

The navigation algorithm for the Smart-Robot is shown in Fig 4. Operation of the SR starts by turning on the master power switch that supplies energy to the power regulator board as in Fig 3. After the device has been powered on, the system will beep and vibrate all finger motors to notify the user that the device is ready for navigation assistance. Through the speaker, the system will ask if the user intends to use a predefined route, or create a new route.

If the user intends to use a predefined route, the system will ask for route origin and destination. Upon input from the user, the system will fetch the route coordinates from the appropriate route file, and load them on a route array \( ra = \{i, i+1, \ldots, k\} \). Next, the system obtains the current longitude and latitude coordinates \( x' \) from the GPS/RFID, and computes the distance and direction from \( x' \) to the next landmark \( i' \). Upon computation of these parameters, the microcontroller sends appropriate signals to the robot motors for navigation.

While in operation, the SR continuously checks for obstacles using the ultrasonic and infrared sensors mounted on the top of design chassis. The ultrasonic sensor detects obstacles relatively straight ahead while the two infrared sensors detect obstacles at a 22.5° angle relative to the front of the robot. To avoid an obstacle, the SR uses inputs from all three sensors. Upon identifying any obstacle in its path, the SR computes a new route to avoid obstacles, and overwrites the route array \( 'ra' \). If only the ultrasonic sensor detects an obstacle, the SR would have to turn left or right appropriately and continue until the opposite infrared sensor clears the object. If only one infrared sensor detects an obstruction, the distance is calculated relative to the robot, and a new routing coordinates are calculated and overwritten on the route array \( 'ra' \). The output of each sensor with respect to its distance is shown in Fig 5.

During travel, the SR provides continuous feedback to the user through the speaker and vibrating motors on the glove. When the SR is about to turn left or right, the motors present on the index finger and ring finger of the glove vibrate to inform the user of appropriate movement. Upon reaching each landmark, the speaker announces the appropriate location information.
If the user intends to create a new route, the system will ask the user for route origin and destination. Accordingly, the direction buttons (left, right, forward, and backwards) will be activated. Later, the user can use these buttons to move the SR to the appropriate destination. Throughout the duration of this travel, the system will record the longitude and latitude coordinates periodically from the RFID while indoors, or from the GPS while outdoors and store them in a route array \( ra = \{i,i+1,...,k\} \). Upon reaching the destination, the user presses the “\#” button to indicate the destination. Accordingly, the route array \( ra \) will be saved into an appropriate route file in the system memory. The route file is then closed and the system returns to the start sequence.

V. PILOT EXPERIMENTS

The Smart-Robot is a work-in-progress and has yet to be tested extensively. To test the system’s ability in addressing the user’s needs, the design team has created appropriate experiments to quantify the performance of SR under a controlled environment. Data was collected and analyzed to validate the reliability of implementing the SR.

The pilot experiments focused on reaching destination with minimum input from the user. The SR was deployed for operation between three buildings on the university campus. Thirty RFID tags were placed outside the walls of a few rooms in each building using small pieces of cardboard to insulate from metal or dirt. Information from these RFID tags is used as landmarks indoor, and GPS coordinates are used for landmarks outdoor.

Three different routes were created and recorded on the system using the algorithm presented in Fig. 4. The design team tested these routes four times with low traffic indoors and outdoors. It was observed that SR reaches the destination with slight variation in travel time. This is due to limited accuracy (≈2m) of the GPS, and RFID system. Research is currently in progress to reduce this variation in travel time by developing effective localization algorithms.

VI. CONCLUSION

The concept of utilizing RFID and GPS for navigation assistance to the visually impaired is both technically and economically feasible. The barrier to entry for this technology is low after efficient RFID and GPS localization algorithms are developed. This Smart-Robot system helps the visually impaired person become less dependent on others to commute, and shows promising incentive in improving the quality of life. Overall, the Smart-Robot could make these routine tasks simple and feasible for a visually impaired person.

REFERENCES


Figure 5: Obstacle Detection Range