Intelligent Guide Robot (I-GUIDE)

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ABSTRACT

The objective of this project is to design an autonomous mobile robot that acts as a tour guide for visitors of the Electrical and Computer Engineering (ECE) Department at Bradley University. The project utilizes a Pioneer 3 Robot as a working platform for the Intelligent Guide Robot (I-GUIDE). Microsoft Visual Studio and ARIA MobileSim software packages are used to program and simulate the Pioneer 3 in C++. I-GUIDE employs a basic wall following and path-planning algorithm with obstacle avoidance and unique landmark detection. The wall following and obstacle avoidance algorithms utilize arrays of infrared and ultrasonic sensors, respectively. Unique landmark detection is provided by ultra-violet sensitive barcodes placed on the ceiling, which are read by an extended range barcode scanner. Path planning is accomplished using an internal topological decomposition map, where each node corresponds to a unique landmark. A user interface, consisting of a keypad, "kiosk" liquid crystal display monitor, and computer speakers, is used to interact with ECE Department visitors. I-GUIDE is currently capable of navigating a single floor, avoiding most obstacles, and reaching an intended location.

Keywords

Mobile robotics; Navigation; Localization; Tour guide robots

1. INTRODUCTION

Many professors in the Electrical and Computer Engineering (ECE) Department at Bradley University spend time giving tours of the facilities, laboratories, and classrooms to prospective students and their families. During the course of these tours, the professors invariably incorporate a visit to the Senior Laboratories where they demonstrate examples of the Senior Capstone Project. I-GUIDE serves the dual purpose of providing an example of a Capstone Project as well as alleviating professors of the requirement to give tours. To serve fully in these functions, the necessary goals for this tour robot are defined below. I-GUIDE must:

- Autonomously navigate the second and third floors of the ECE Department.
- Utilize the elevator as a means of transportation between floors. (Due to the complexity of this problem, elevator operation is not completely autonomous and some user assistance is required.)
- Perform obstacle detection and autonomously navigate around obstacles.
- Autonomously locate predefined points of interest throughout the ECE Department and provide audio and visual feedback while facing the user.
- Detect when the battery is low and autonomously locate the Pioneer docking station.

This paper discusses the five main software modules, the hardware necessary for each module, and the design choices that drove the development of each. It also includes a discussion of the results and future work.

1.1 Development Tools

I-GUIDE is an autonomous mobile robot that is built on the Pioneer 3 platform from ActivMedia, programmed using Microsoft Visual Studio and ARIA MobileSim Software, and simulated in the ARIA Mapper program. Most of the code written for this project is in C++, with a few driver modules written in C.

1.1.1 Pioneer 3

The Pioneer 3 platform comes equipped with many integrated onboard components including: 8 ultrasonic sensors, rotary encoders on both motors, a serial communications interface, and three 12V batteries wired in parallel. The base model is shown in Figure 1. Note: The gripper seen on the front of the Pioneer 3 in Figure 1 does not come standard with the base platform. It was a post-production addition for a previous project.

Figure 1 - Pioneer 3 Base Model

Figure 2 - To-Scale Model of 2nd Floor (Ideal)

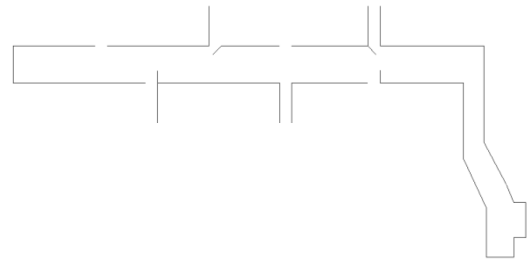

Figure 3 - To-Scale Model of 2nd Floor (Worst-Case)

1.1.2 ARIA Mapper

ARIA Mapper allows the creation of a highly detailed, precise, randomized environment. Utilizing this program, a simulation was created for both ideal and worst-case scenarios. Figure 2 shows a map of the ideal 2^{nd} floor environment, meaning there are no open doors or alcoves. Figure 3 shows a map of the same floor, except it includes open doors and alcoves.

2. SYSTEM COMPONENTS

The high-level diagram in Figure 4 shows the overall system hardware. The human-interface device, consisting of a keypad, speakers, and monitor, is connected to the laptop via the standard interfaces; i.e. USB port, 3.5 mm stereo jack, and VGA port, respectively. The laptop is connected to the Pioneer using the serial port. The infrared (IR) sensors produce an analog signal that is read by an Analog to Digital to Universal Serial Bus Converter (ADC-USB), which in turn is read by the laptop. The laptop provides power to the barcode scanner and the scanner is triggered by a digital output on the ADC-USB. Because the ultrasonic sensors are already built into the Pioneer, their outputs are read from the Pioneer to the laptop. The laptop also runs I-GUIDE's software, which consists of five main modules: Initialization, Wall Following, Obstacle Detection & Avoidance, Path Planning & Localization, and User Interface.

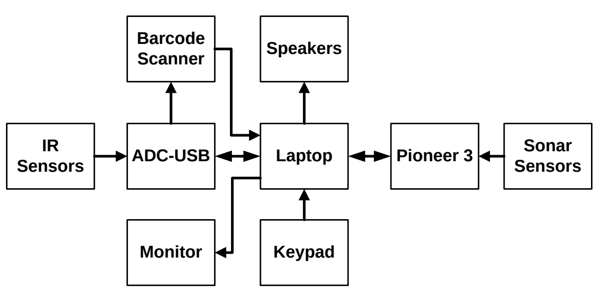

Figure 4 - Overall System Block Diagram

2.1 Initialization

The initialization algorithm attempts to connect to the Pioneer 3 over the serial port, open a stream to the ADC-USB over USB, and check that the other peripherals are connected. Should any of these fail, I-GUIDE logs which device failed, closes the other initialized devices, and exits the program.

After successfully opening and connecting to all of the devices, I-GUIDE runs through a calibration sequence to place itself squarely in the center of the hallway and parallel to both walls. This is achieved by reading data from a bank of 8 IR sensors.

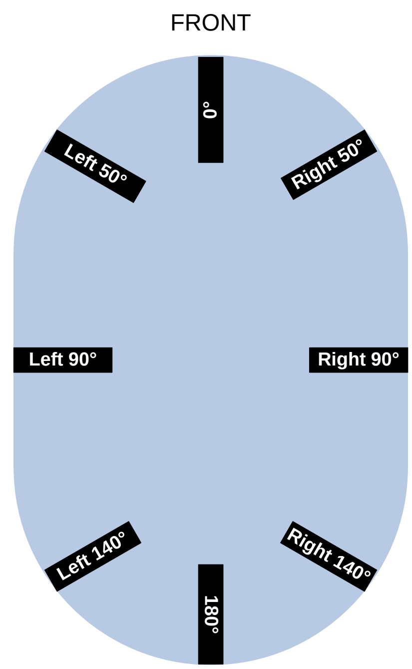

Figure 5 – IR Sensor Layout

2.1.1 Infrared Sensors

As shown in Figure 5, the IR sensors are placed onto the robot at 0°, left and right 50°, left and right 90°, left and right 140°, and, lastly, 180° from the front of the robot. The IR sensors are capable of producing measurements accurate to within 3.2 cm for distances up to 90 cm. The sensors are powered by the Pioneer 3's internal batteries through a voltage regulator.

Since the IR sensor outputs are analog voltages, an ADC-USB is used to transfer the sensor measurements to the laptop. A 100kΩ resistor is necessary between each of the

ADC-USB inputs and ground because of the high input impedance of the IR sensors. This high input impedance allows current transients internal to the ADC-USB to affect the sensor voltage readings. The 100kΩ resistor shunts these current transients to ground allowing the IR sensor's true output voltage to be read at the input to the ADC-USB.

2.1.2 Calibration

The calibration algorithm flowchart is shown in Figure 7. The first step in calibration is to drive to the center of the hallway. Analyzing data from the IR sensors, I-GUIDE calculates its actual distance from both walls using the following calculations, graphically shown in Figure 6:

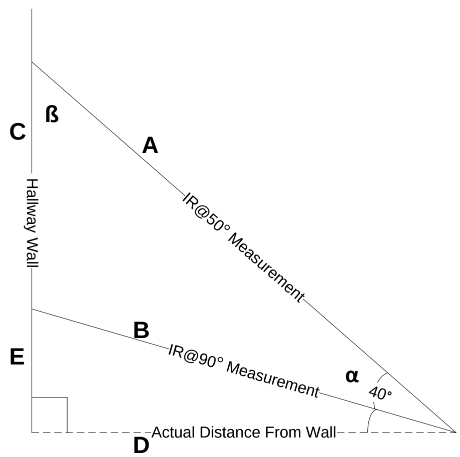

Figure 6 – Geometric Example

$$Law\ of\ cosines: C^2 = A^2 + B^2 - 2AB\cos(\alpha)$$

$$Law\ of\ cosines: \cos(\beta) = \frac{A^2 + C^2 - B^2}{2AC}$$

$$Law\ of\ sines: \frac{\sin(\beta)}{D} = \frac{\sin(90°)}{A}$$

$$A\sin\left(\cos^{-1}\left(\frac{A^2 + C^2 - B^2}{2AC}\right)\right) = D$$

$$Reduced\ Form: A\left(\sqrt{1 - \left(\frac{A^2 + C^2 - B^2}{2AC}\right)^2}\right) = D$$

$$Angle\ from\ Parallel: \cos^{-1}\left(\frac{A}{D}\right)\ (in\ radians)$$

Knowing the orientation of the robot with respect to the walls, I-GUIDE can turn directly towards the wall that is furthest away by rotating 90° ± <Angle from Parallel>. Utilizing the IR sensor at 0° and 180°, I-GUIDE centers itself by driving forward until the distance ahead is equal to the distance behind. I-GUIDE then rotates 90° orienting itself so that it is parallel to both walls and ready to drive down the hallway.

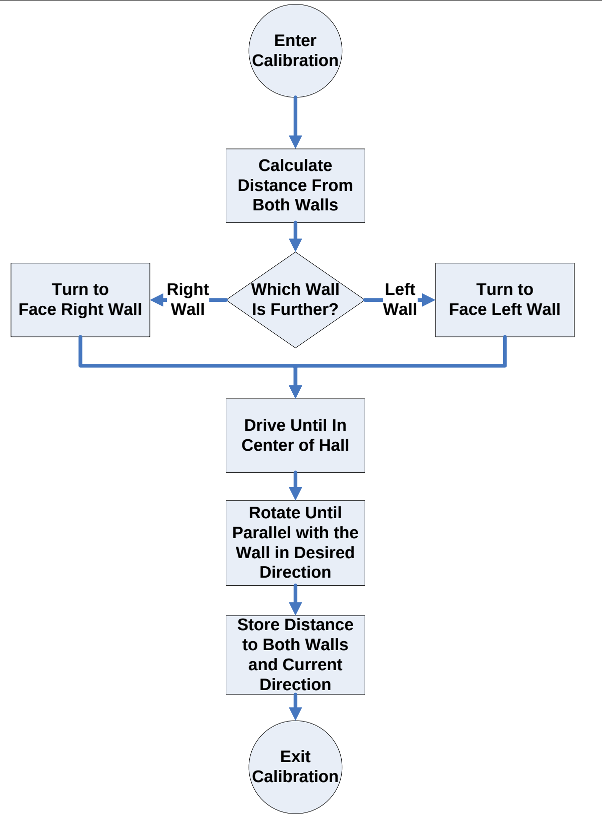

Figure 7 – Calibration Flow Chart

2.2 Wall Following Algorithm

The wall following algorithm employs the 90° and 50° IR sensors on both left and right sides to detect the distance between the robot and the wall. Driving in the middle third of the hallway, shown as a blue-dotted line in Figure 10, is crucial to I-GUIDE's operation. Both localization and path planning algorithms depend on the detection of unique landmarks (barcodes) that can only be detected when I-GUIDE is in the middle third of the hallway.

The wall following algorithm flowchart is shown in Figure 8. The algorithm sets I-GUIDE's driving speed to 60 cm/sec, which is slightly slower than the average human walking rate of 80 cm/sec [1]. I-GUIDE's driving speed was selected to allow a group of people to follow easily. The algorithm continually calculates the distance to both walls and compares this distance to the distance determined at calibration. Knowing the calibrated distance to both walls enables I-GUIDE to distinguish between the real wall and static obstacles in the hallway, such as bookcases and open doors. While real walls are detected by the IR sensors, I-GUIDE uses either the right wall, left wall, or both walls to determine whether it is in the middle third of the hallway. Should there be an obstacle on both walls, I-GUIDE uses dead reckoning to remain in the center of the hallway.

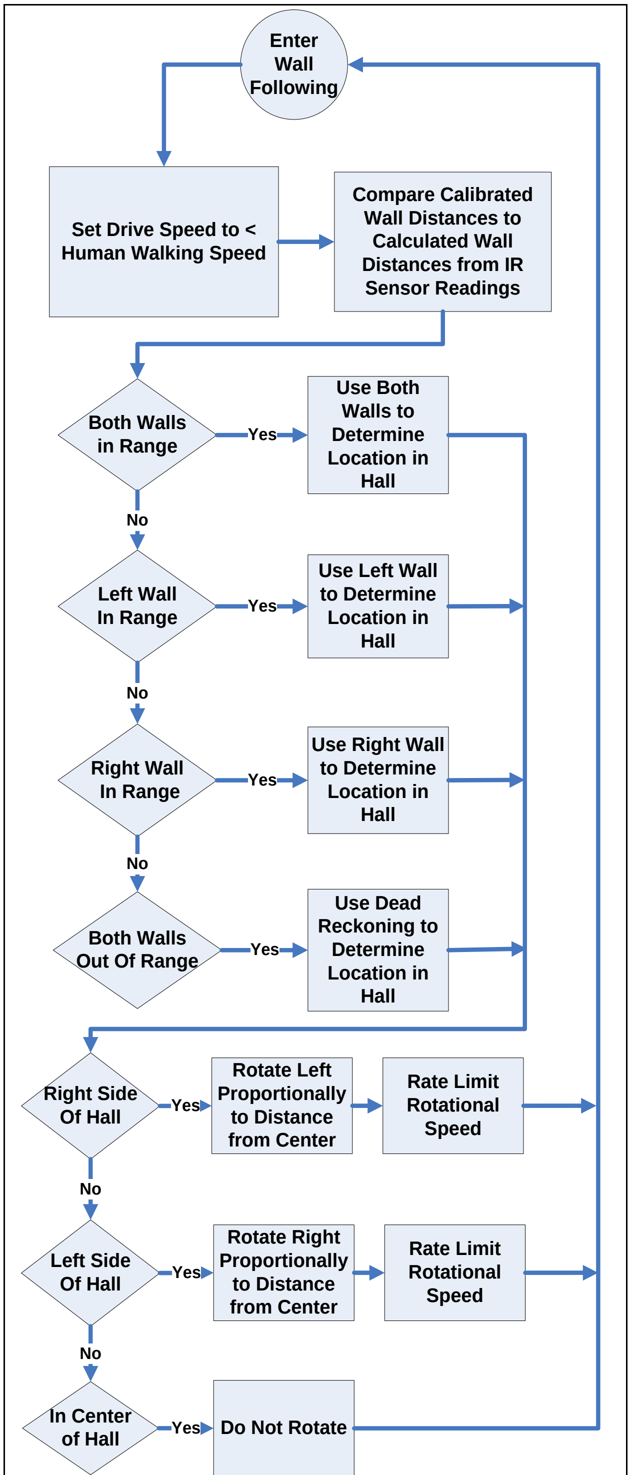

Figure 8 – Wall Following Algorithm

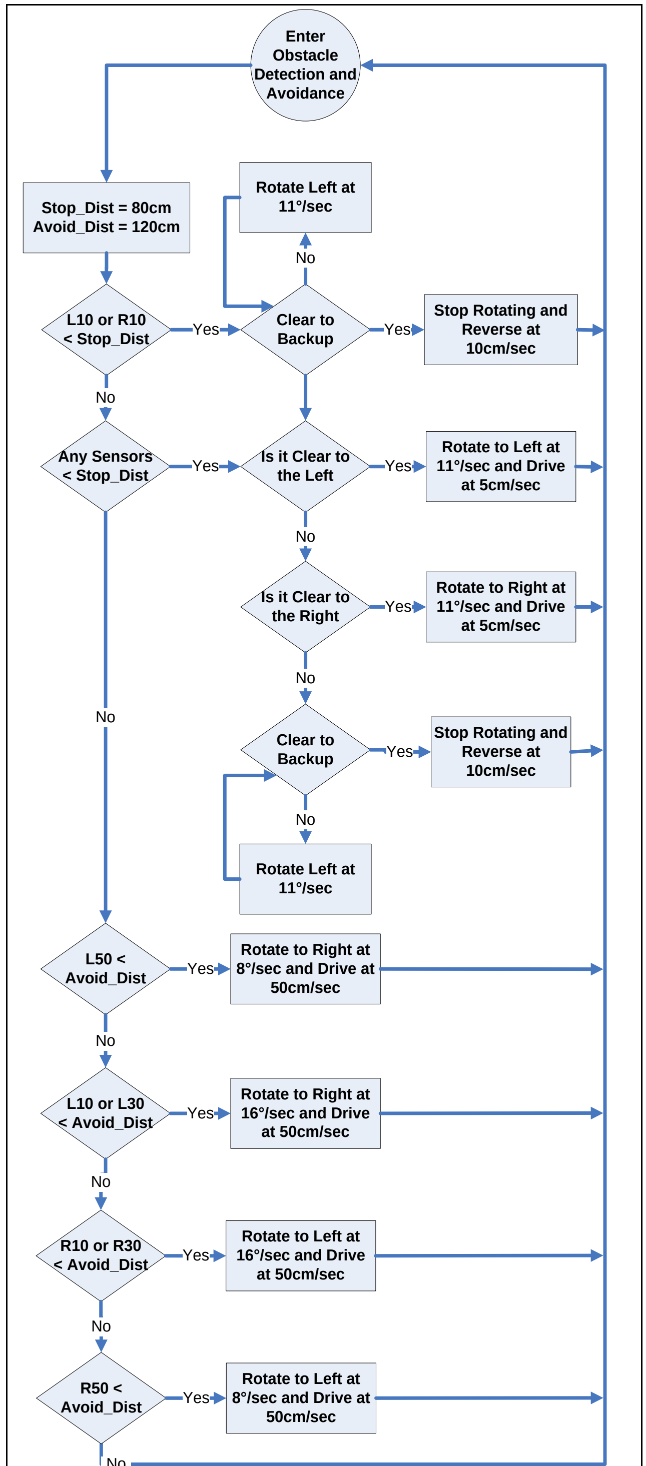

Figure 9 – Obstacle Detection and Avoidance Algorithm

Whenever the robot detects that it is outside of the middle third of the hallway, it rotates back towards the center. The speed of rotation is scaled proportionally to the distance of the robot from the center of the hallway. To prevent overshoot and oscillation, the rotation speed is rate limited, enabling a smooth return to the middle of the hall.

Figure 10 depicts three sample simulation test runs where the robot begins at various locations outside of the middle third of the hallway. As can be seen, the algorithm smoothly and efficiently guides the robot into the center region of the hallway.

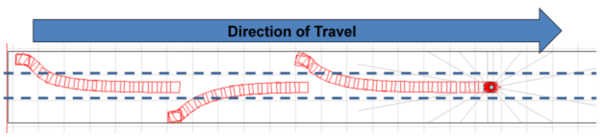

Figure 10 – Wall Following Simulation

2.3 Obstacle Detection & Avoidance

Obstacle detection and avoidance is implemented using a combination of ultrasonic and IR sensors to detect static and dynamic obstructions. In most situations, ultrasonic sensors are used for obstacle detection. However, since none of the 8 ultrasonic sensors are oriented towards the rear of the platform, IR sensors are employed when I-GUIDE drives in reverse.

The algorithm attempts to avoid obstacles by executing any of a number of possible actions, as shown in Figure 9. When an object enters the robot's field of vision at distances less than 120 cm, I-GUIDE slows down and adjusts its path. If an obstacle is detected below 80 cm, however, I-GUIDE performs a more specialized obstacle avoidance routine.

The specialized routine for objects closer than 80 cm checks the ultrasonic sensor readings to determine the best course of action. If there are any obstacles directly ahead, I-GUIDE stops and reverses. Otherwise, the obstacles must be located on either the right or left side of the robot. I-GUIDE determines which side of the robot is free of obstacles and drives in that direction.

Lastly, bump sensors have been designed as a fail-safe for the robot to stop and reverse should it bump into anything.

2.3.1 Ultrasonic Sensors

The Pioneer 3 platform comes equipped with an array of 8 ultrasonic sensors. Unfortunately, the halls of the ECE Department are covered with highly specular tiles that cause the majority of the ultrasonic signals to be reflected with little backscatter. The result is that the ultrasonic sensors are incapable of detecting a wall unless the sensors are nearly perpendicular to the wall. However, the ultrasonic sensors are significantly more reliable than the IR sensors when detecting obstacles in close proximity. The minimum range for the IR sensors is 75 cm, whereas, the ultrasonic sensors can accurately detect obstacles as close as 15 cm. For this reason, the ultrasonic sensors are used solely for obstacle detection.

2.3.2 Bump Sensors

I-GUIDE is designed to have two bumps sensors. One sensor covers from the left and right 90° sensors forward, while the other covers from the left and right 90° sensors backward. The bump sensors provide a digital input when triggered, which is transferred to the laptop via the ADC-USB.

2.4 Path Planning & Localization

Path planning and localization are accomplished primarily though an internal topological decomposition map and unique landmark detection using a long range barcode scanner to read barcodes off of the ceiling.

2.4.1 Topological Decomposition

Since I-GUIDE is primarily built for a known environment, a mapping technique known as topological decomposition is implemented. This technique identifies key nodes in an environment and the connectivity between them. The connectivity also contains the angle for each arch between nodes. Figure 11 shows an example topological decomposition map of an environment.

The topological decomposition map is programmed into I-GUIDE with each node being a point of interest or landmark. Each node contains information regarding the other nodes that can be directly reached from it, the direction necessary to reach these nodes, and the approximate distance to the nodes. This way, when a node is reached, the robot can determine its next path to any particular node.

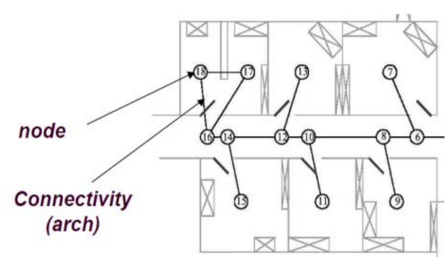

Figure 11 – Example Topological Decomposition Map [2]

2.4.2 Localization

Localization is achieved by detecting unique landmarks within the operating environment. These landmarks are made up of ultra-violet (UV) sensitive ink barcodes placed on the ceiling [3]. Each barcode corresponds to a node on the topological decomposition map and is read by an extended range barcode scanner mounted on the platform.

2.4.3 Barcode Scanner

I-GUIDE is equipped with an extended range barcode scanner which typically reads barcodes at a distance of 9 feet. However, it is capable of reading barcodes up to 17 feet away. Each barcode is encoded with the floor number and a numerical value using the UPC-E barcode scheme.

The barcode scanner is powered directly off the laptop via a USB interface. It is activated through a digital output on the ADC-USB, which only activates the scanner when I-GUIDE is in close proximity to a barcode. This provides a minimal drain on the laptop's battery and a limited possibility of human exposure to a Class 2 laser. The barcode scanner is read by the software as a keyboard input.

I-GUIDE can determine when it is in close proximity to a barcode based on the previously detected barcode and the maximum distance traveled. Each barcode is coded into software with the distance to the next one. The maximum distance traveled is determined by dead reckoning. The Pioneer 3 has a built-in dead reckoning system calculated from wheel turns by a rotary encoder. The barcode scanner is activated shortly before dead reckoning indicates that the robot will arrive at the next landmark. Because dead reckoning is an idealized maximum distance, this guarantees that the scanner will be operating when the robot passes under the next barcode.

2.4.4 Path Planning

I-GUIDE determines the path to its next objective based on its current position and the final position necessary for the robot. Landmarks are encoded in ascending order, which allows a difference equation to determine the direction the robot must travel. Once the direction of travel is attained and a proper orientation is set, the robot drives forward using wall following algorithm until it reaches the next landmark and checks if it is the final destination.

2.4.5 Current Orientation

I-GUIDE tracks its orientation based on the difference between each landmark. Based on whether the landmark values are increasing or decreasing, it can determine its current bearing. Should I-GUIDE become disoriented, it only needs to travel to the next landmark and compare its value to the last landmark visited. By calculating the difference between the two landmark values, it can easily determine whether it is traveling in the correct direction. Because the hallway has only two general directions, it is unlikely for I-GUIDE to become disoriented frequently.

2.5 User Interface

Part of I-GUIDE's design is to include a means of interacting with its human operators. This includes a means of choosing a desired tour or location and providing audio/video feedback to the user. The visual interface is programmed as a graphical user interface (GUI) in C#.

2.5.1 Monitor

A small "kiosk" monitor is mounted to provide users with video while I-GUIDE is giving a tour. The monitor is powered off the Pioneer 3's internal batteries via a voltage regulator. The monitor is capable of running as low as 8V, which allows it to provide warnings before the robot turns off. The monitor is connected to the laptop through a VGA port and is accessed as an extended desktop on the Windows XP operating system. Video will be played through the GUI.

2.5.2 Speakers

To provide audio to accompany the video, a pair of speakers is mounted on I-GUIDE. The speakers are powered and connected by a 3.5 mm stereo jack to the laptop. The audio playback is initiated by the GUI.

2.5.3 Numerical Keypad

As a means of allowing a user to input a desired location or tour, a numerical keypad is provided. The keypad is connected to the laptop through a USB port, read by the software as a keyboard input, and powered through the USB connection.

3. SUBSUMPTION ARCHITECTURE

The three software modules that run as continuous loops are Path Planning & Localization, Obstacle Detection & Avoidance, and Wall Following

These three algorithms are setup to run in a subsumption architecture, as illustrated in Figure 12. Subsumption architecture breaks a complex intelligent behavior into smaller behavior modules that are arranged in hierarchical layers, where one algorithm can "subsume" another.

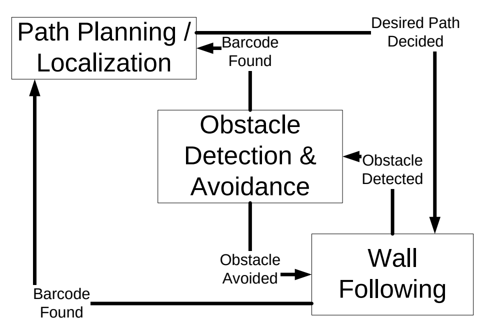

Figure 12 – Subsumption Architecture

The base level Wall Following algorithm only relinquishes control of I-GUIDE if either an obstacle or barcode is found. Obstacle Detection & Avoidance relinquishes control when either a barcode is found or the obstacle has been avoided. Lastly, the Path Planning & Localization algorithm only releases control when it has set the desired path.

4. RESULTS

I-GUIDE can successfully drive down the center third of the second floor of the ECE department. While doing so, it can detect and avoid most obstacles and read barcodes off the ceiling.

One of the most difficult tasks was the basic wall following algorithm. In an ideal environment, wall following is simple. However, in the real environment there are doors which open out into the hall, doors that open inward into rooms, and variations in the wall distances due to static objects like bookcases. I-GUIDE perceives these objects as changes in the distance to the wall. This causes the robot to veer away from the center of the hallway. Because the entire localization algorithm is dependent upon the robot's ability to stay in the middle third of the hall, further development of the third floor navigation is still underway.

Due to time constraints, the GUI is not complete and the speakers, monitor, and user keypad are not fully integrated. Because of this, I-GUIDE is not fully operational and cannot give tours at this time.

5. FUTURE WORK

Currently, I-GUIDE is only able to navigate the second floor in the ECE department. To make the project fully operational, several additional situations must be overcome. Interaction with an elevator, implementation of the topological decomposition map of the first and third floor, and traversing a handicap-accessible ramp must all be properly integrated into I-GUIDE.

5.1 Elevator

The robot can reach the elevator on the second floor but cannot activate the elevator call button. I-GUIDE still needs to learn how to ask someone to push the correct elevator button and navigate into the elevator. A future implementation of I-GUIDE could include a camera to identify the elevator buttons and a mechanical arm to push the call button.

5.2 Third Floor of the ECE Department

Once the elevator issue is resolved, a map must be coded for the third floor, as well as the accompanying audio/video for each landmark.

5.3 First Floor of the ECE Department

After I-GUIDE can successfully travel to the first floor, it must be able to traverse a handicap-accessible ramp. This requires fine navigational control of the robot with special instructions for speed, rotation, and error checking. Special IR or sonar sensors must be placed at the height of the rails along the ramp for navigational purposes.

6. CONCLUSIONS

I-GUIDE provides not only a working demonstration of a Senior Capstone project, but also an autonomous tour guide to relieve professors of the necessity to give tours. Furthermore, the platform can serve as a foundation for future projects. With the integrated IR sensors, barcode scanner, monitor, additional channels on the ADC-USB, and a means in which to navigate the ECE Department accurately, additional projects can focus on the more advanced applications of robotics.

7. ACKNOWLEDGMENTS

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