# A Semi-Autonomous Navigational System for the Visually Impaired

Daniel Haas, Shawn Mothersell, Daniel Nielsen, Kumar Yelamarthi
Central Michigan University, {haas1d, mothe1sw, niels1dj, yelam1k}@cmich.edu

***Abstract*** **- According to the *National Center for Health Statistics* approximately 1.3 million people in the United States are legally blind. Two of the primary challenges that visually impaired people face every day are mobility and orientation. Less than 10% of visually impaired people use canes and approximately 5% use guide dogs. The project scope is to develop a working prototype using ultrasonic and infrared sensors along with radio frequency identification (RFID) and global positioning (GPS) technologies to help a visually impaired person navigate safely. The *Smart-Robot* will incorporate knowledge gained from a 2008 senior design project referred to as the 'Smart Cane.' The design of the *Smart-Robot* will encourage further exploration into navigational systems to help increase the safety and mobility of the visually impaired community.**

*Index Terms* – embedded systems, navigation, robotics, and senior design.

## INTRODUCTION

The *National Center for Health Statistics* states that approximately 1.3 million people in the United States are visually impaired [1]. Of these people, more than 100,000 use white canes and approximately 7,000 use dog guides for navigation [2]. Guide dogs, also known as "seeing eye dogs" can be a very useful tool for navigation when properly trained. However, the use of guide dogs for navigation is not widespread due to the lack of trainers and training facilities. In addition, a guide dog can cost in excess of $38,000 to train [3]. 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 extra cost of a guide dog. Even after training and implementation costs, a guide dog can only provide limited assistance. Overhanging obstacles such as tree branches often go undetected by a guide dog, creating significant safety hazards. A visually impaired person with all the proper training and equipment still may not feel comfortable or safe in their environment.

The *Smart-Robot* is a senior design project that aims to make life easier for the visually impaired. Specifically, those who make the same trips each day would benefit from using the *Smart-Robot*. By incorporating navigation devices such as GPS and RFID systems, along with obstacle detection sensors; safety and navigation are significantly increased when compared to historically used devices.

## PREVIOUS WORK

Some devices have been designed in the past to improve commute for the visually impaired including an electronic travel aid, referred to as the "Miniguide." The "Miniguide" uses ultra-sonic echo location to detect objects at varying distances [4]. This device is a handheld unit with a push button to change the mode of operation. It detects obstacles at five different distances referred to as operating modes. The unit vibrates to notify the user of obstacles in the immediate path. The closer the object is from the user, the faster the "Miniguide" vibrates. The "Miniguide" does have disadvantages. For instance, it cannot detect drop-offs such as curbs and steps and has no navigational assistance included to help guide the user from place to place.

Another device, called the "Laser Cane," uses three lasers mounted on the cane, each at a different angle [5]. Each laser corresponds to an individual tone so the user can identify which laser encountered an obstacle. One laser points at the ground detecting a drop in elevation, the second points straight in front of the user at an angle parallel to the ground, and the third points straight ahead at an angle of 45 degrees upwards to protect the upper body from overhanging obstacles. Disadvantages of the "Laser Cane" include: no navigational assistance, cost, and other anomalies. One reported problem is when the downward pointing laser is aimed at a puddle; the tone is triggered to inform the user of a drop off when actually it does not exist. Also, differences in the orientation that a user holds the cane affect the direction of the lasers causing false tones to sound. In addition, electronic components are exclusive to the "Laser Cane" and cannot be easily obtained making repairs timely and expensive.

The "Smart Cane", designed by a 2008 CMU senior design team, used a RFID system to navigate a user from building to building along a predefined path. An ultrasonic sensor mounted on the cane was used for obstacle avoidance. The device used a combination of vibration motors and audible tones to notify the user when to turn, stop, or continue. Each RFID tag stored information that was retrieved when the tag was excited by the antenna. The activated tag relayed the information back to the reader when the tag was in range. However, RFID tags have a limited range and the distance and direction relative to the antenna cannot be determined. Therefore, the user could still be in range of the tag but may not have been walking on the sidewalk or desired walking path. In addition, the ultrasonic sensor mounted on the cane had a limited range of obstacle detection close to the length of the cane itself.

The proposed *Smart-Robot* can overcome the limitations that canes, dogs, and previous products have. All of the components in the *Smart-Robot* are off-the-shelf products which are easy to find and are also affordable. The accuracy of the GPS unit (<=2m) is high enough to keep the user on the sidewalk. If the user enters a building where the GPS has no reception, the RFID and object detection systems will continue to work. Therefore, the user can successfully use the *Smart-Robot* to safely navigate indoors and outdoors.

## SYSTEM DESIGN

The objective of *Smart-Robot* is to develop a navigation system where a visually impaired student can navigate from the Engineering Technology building to the Park Library, or student housing, and vice versa. The navigation system must also have the ability to program a route "on-the-fly" and store it in the memory for later use. In addition, an embedded system must be designed that can identify the location from RFID tags, and generate appropriate signals to assist the user in reaching a predefined location. The signals generated should include an audible signal to inform the user of the direction to pursue, and another form of signal in case the visually impaired user is also deaf. The *Smart-Robot* is equipped with RFID system, GPS, and object detection hardware. In order to navigate between destinations each day, the required battery life was estimated to be 3 hours per charge. The battery will allow for multiple trips per day on a single charge.

The block diagram of *Smart-Robot* is shown in Figure 1. The brain of the system is the Motorola 68HCS12 microcontroller. The input from the user is through a 4x4 hex keypad. Other input devices are used for navigation, orientation, and obstacle detection. The GPS unit is a *Garmin* OEM 18x5Hz. The RFID system is a DKM9 - *SkyeModule* M9 developer kit operating at 915 MHz. The obstacle avoidance sensors are two *Sharp* GP2D12 infrared (IR) sensors and a *MAXBotix* MaxSonar EZ0 ultrasonic sensor. The orientation sensor is a *Robson* 1655 analog compass. There are four outputs from the microcontroller. The two user feedback signals are a small speaker and a glove with 10-mm shaft-less vibration motors on the index, middle and ring fingers. The on-board LCD display is used for displaying text for troubleshooting purposes. A *Sparkfun Electronics* Logomatic v2 equipped with a micro-SD card and an altered firmware is used for file creation, modification, and deletion.

All of the electronic components are mounted on a pre-made chassis. The tires are 5" medium terrain tires driven by 30-mm DC motors with 6mm wheel adapters. The GPS, RFID antenna, and the three sensors are mounted outside the chassis. The other hardware including the 14.8V 6600mAh battery is enclosed inside. A photograph of the *Smart-Robot* prototype is shown in Figure 2.

The components of the *Smart-Robot* all require different voltage levels, ranging from 3.3 to 12 volts. In order to use a single power source a power bus is required. The power bus steps down the battery voltage to the desired levels, and protects each system from current overflow. The GPS, Ultrasonic sensors, IR sensors and RFID all require 5 volts. As the RFID system consumes a relatively large amount of current, it requires its own voltage regulator and fuse. The DC motors, microcontroller and vibration motors all require different voltage regulators with 12, 9 and 3.3 volts respectively. The fuses protecting each component are *Tyco* Polymeric Temperature Coefficient (PTC) resettable fuses with trip currents ranging from 0.3 to 2.5 amps. A switch in the power bus will allow the user to turn the *Smart-Robot* on and off. The power bus schematic is shown in Figure 3.

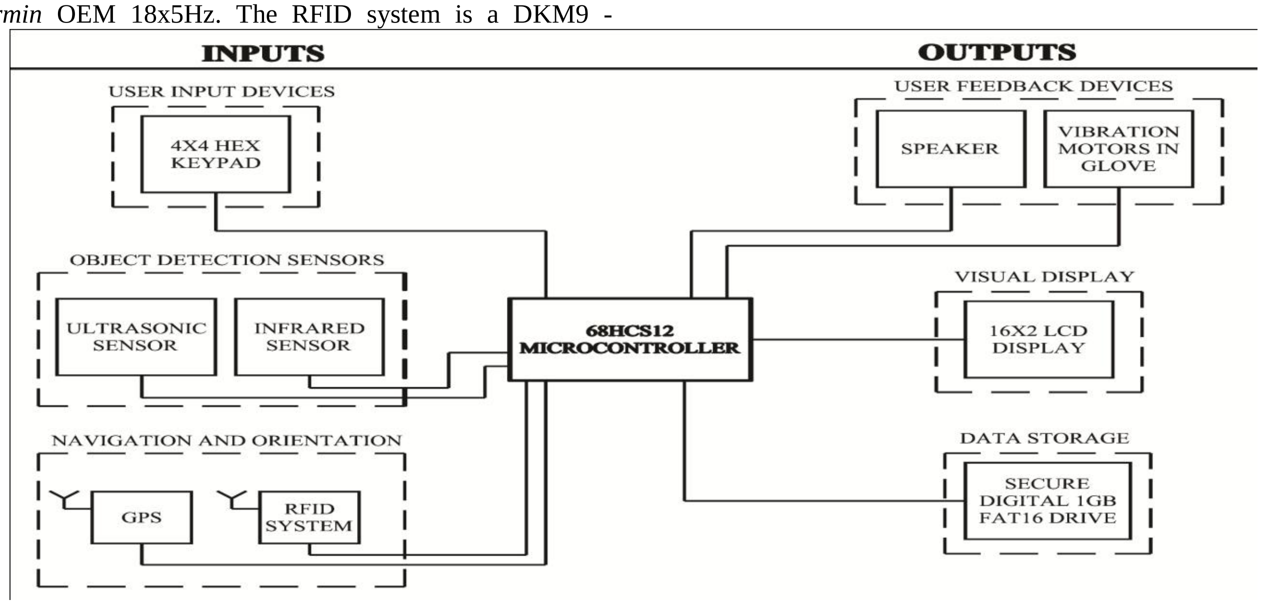


FIGURE 1 – SMART-ROBOT BLOCK DIAGRAM

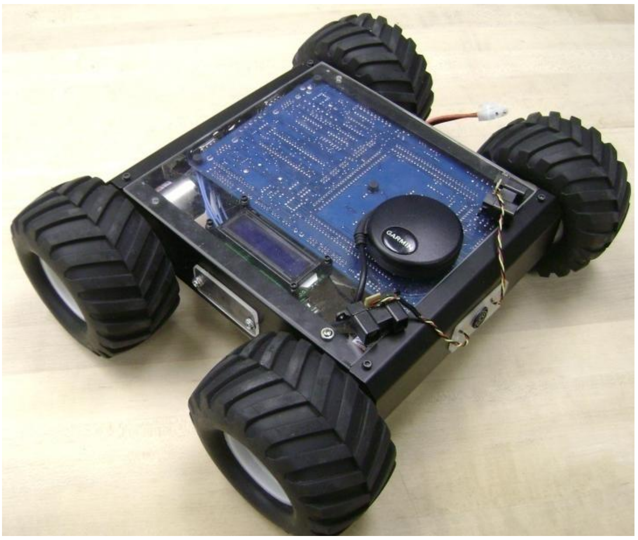

FIGURE 2 – *SMART-ROBOT* PROTOTYPE

The components of the *Smart-Robot* have a combined maximum current consumption of 3005 mA. However, rarely will the device require maximum power. This implies that a 9015 mAH (3005 mA x 3 hours) battery will not be necessary to run the robot for three hours. Instead, with the assumption that the robot will operate between 50% and 75% power, a 6600 mAH 14.8 V battery is sufficient to allow the user to commute for at least three hours. A lithium ion battery was chosen to power the hardware as opposed to a Nickel Cadmium battery because it is lighter, has a faster charge time, and a longer lifespan. Power consumption of each hardware unit is shown in Table 1.

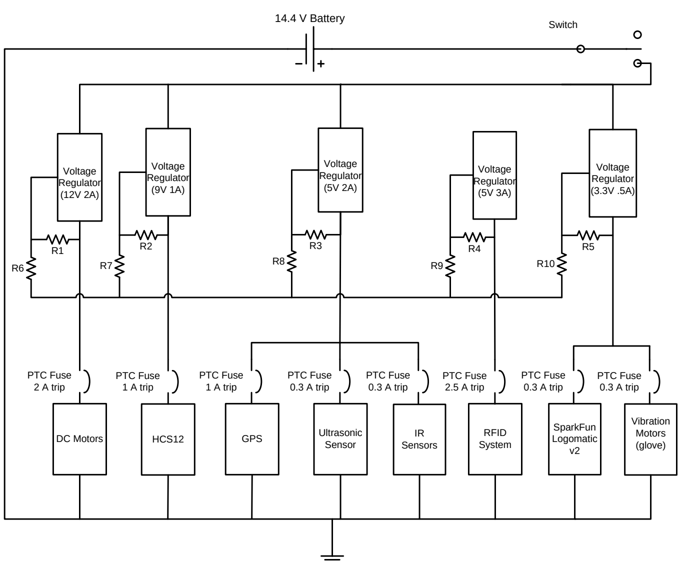


FIGURE 3 – *SMART-ROBOT* POWER BUS SCHEMATIC

TABLE 1 –HARDWARE POWER CONSUMPTION

| Components | Max Current (mA) | Input Voltage (V) | Max Power (W) |
|---|---|---|---|
| 68HCS12 Microcontroller | 800 | 9.0 | 7.20 |
| Logomatic v2 | 80 | 3.3 | 0.26 |
| Garmin GPS | 100 | 5.0 | 0.50 |
| RFID Developer Kit | 800 | 5.0 | 4.00 |
| Vibration motors | 3x75 | 3.3 | 0.74 |
| Ultrasonic Sensor | 100 | 5.0 | 0.50 |
| Infrared Sensors | 2x50 | 5.0 | 0.50 |
| DC Motors | 4x200 | 12.0 | 9.60 |
| Total | 3005 | | 23.31 |

## ECONOMICS

One of the primary reasons the *Smart-Robot* was developed was to overcome the financial barrier that implementing a guide dog can impose. As stated previously, a guide dog can cost in excess of $38,000. Some people are willing to pay the price to increase their safety, mobility and quality of life. Others that cannot afford or obtain a guide dog have limited alternatives. The *Smart-Robot* utilizes “off-the-shelf” components thereby reducing cost to the end user. Implementation is done by training the user, and creating a few new routes. The preliminary training could easily be accomplished in less than one day. From then on, the user will become increasingly more familiar with the signals and delays increasing their efficiency. Because the *Smart-Robot* has little overhead due to training and utilizes “off the shelf” components; the device could easily be released into the retail market at a price much less than the cost of a guide dog. The total material cost excluding the RFID system is approximately $1,000.

## OPERATION

Operation of the *Smart-Robot* starts by turning on the master power switch that supplies energy to the power regulator board. 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 user input. The system also displays command messages on a LCD display for troubleshooting purposes. From this point the user enters a path number using the standard 4x4 keypad. The system then checks if the route file is a pre-existing one or if a new file needs to be created. A visually impaired person will require assistance when setting up a new route.

If the route is a new one, the controller will create a route file and wait for a start or exit signal. Pressing the “#” character starts the data-logging sequence. The current location is then saved and the device is ready to log the path. The path must then be navigated by the robot. The user can either pick the *Smart-Robot* up and walk to the final destination, or manually drive the robot with use of the hex keypad. Throughout the trip, GPS coordinates are retrieved in the form of a standard NMEA 0183 sentence which is then data-parsed to retrieve the latitude and longitude and stored to a Secure Digital (SD) card. The coordinates are saved sequentially until the "#" character is pressed again, saving the final location. The route file is then closed and the system returns to the start sequence.

If the microcontroller determines that a prerecorded route exists; the route is loaded to an array and the robot will begin guiding the user to the destination. Navigation is done by comparing current position data to pre-recorded position data until the final position coordinates are reached. In addition, the RFID system continually checks for RFID tags which are placed at strategic locations around campus. Orientation is achieved with the use of an analog compass. The user is informed on how to navigate with a series of beeps and vibration signals. A navigational flow chart for the *Smart-Robot* is shown in Figure 4.

During travel, the two infrared sensors along with the ultrasonic sensor continuously check for objects directly in the path of the *Smart-Robot*. The ultrasonic sensor detects obstacles straight ahead while the two infrared sensors are mounted at a 22.5$^{o}$ angle relative to the front of the robot. A schematic of the three sensors and the robot is shown in Figure 5. To avoid an obstacle, the robot uses all three sensor inputs. If only the ultrasonic sensor detects an obstacle, then it must be directly ahead and the robot would turn left or right 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. If the object is determined to be not in the walking path, no turn is necessary. Finally, if all three sensors are triggered, then the object is either too large or most likely a wall. In this case, the robot stops moving and the user will require assistance to a safer path.

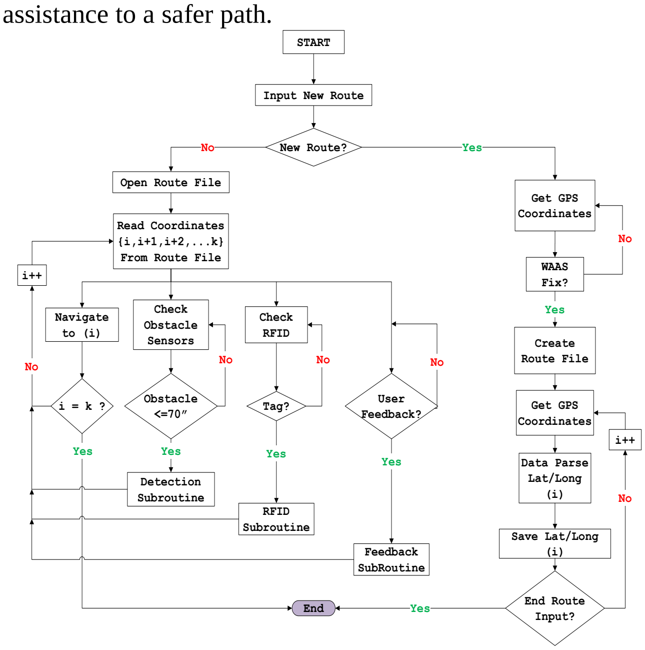


FIGURE 4 – *SMART-ROBOT* NAVIGATIONAL FLOWCHART

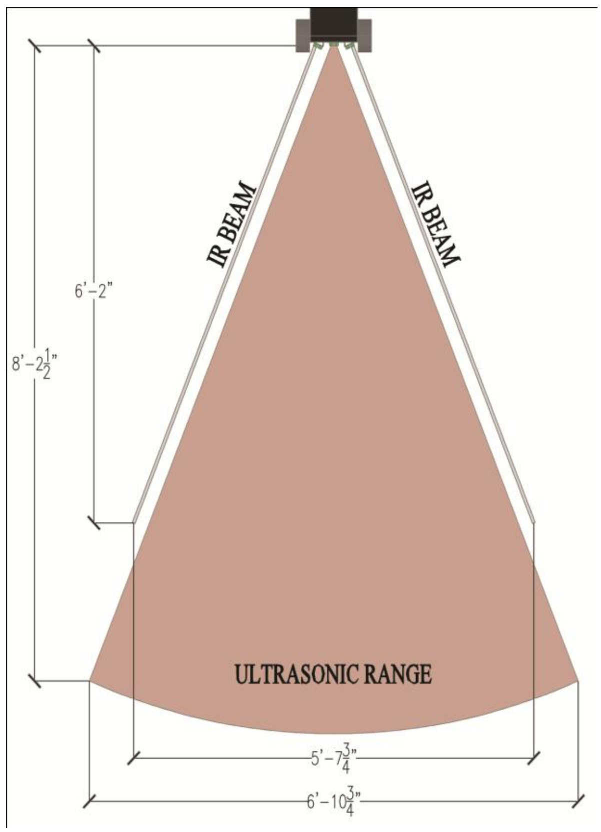


FIGURE 5 – ULTRASONIC AND INFRARED SENSOR BEAM PATTERNS AND TYPICAL READING RANGES

## TESTING AND CALIBRATION

The *Smart-Robot* is a work-in-progress and has yet to be fully tested. To test the system's ability in addressing the user's needs, the team has designed appropriate tests to quantify the performance of the system under a controlled environment. Data will be collected and analyzed to validate the feasibility of actually implementing the *Smart-Robot*. Before the robot can be fully tested, all of the hardware must be calibrated correctly.

The IR and ultrasonic sensors were calibrated in a similar fashion. Calibration tests were conducted by obtaining voltage measurements of the sensors outputs at one inch increments throughout the entire range of the sensors. The actual distance to the object was plotted versus the output voltage reading. By truncating the first fourteen inches of the sensors reading range the function could be successfully modeled by a third degree polynomial as shown in Figure 6 and Figure 7.

The compass was calibrated by placing it on a breadboard and reading the output voltages at 30 degree increments. A plot of the compass's output voltage versus degree of rotation is shown in Figure 8.

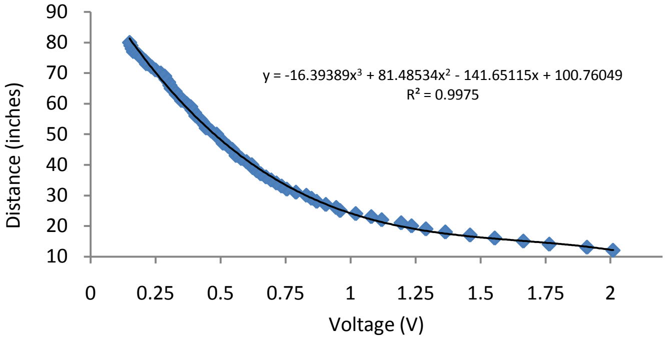


FIGURE 6 – PLOT OF OBJECT DISTANCE VERSUS OUTPUT VOLTAGE OF A SHARP ANALOG IR SENSOR

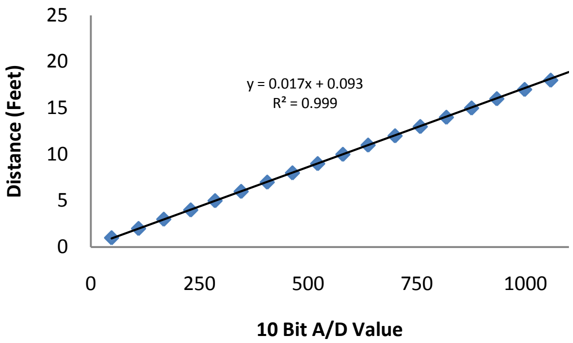


FIGURE 7 – PLOT OF OBJECT DISTANCE VERSUS OUTPUT VOLTAGE OF A MAXBOTIX ANALOG ULTRASONIC SENSOR

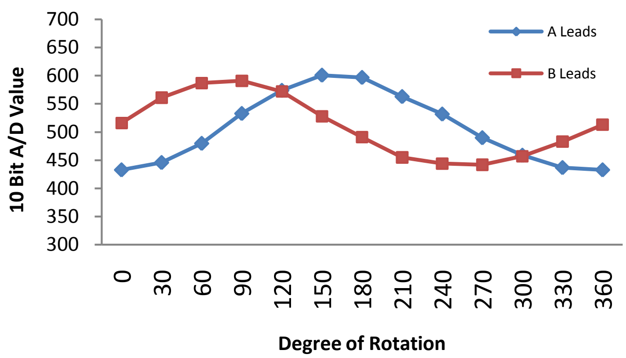


FIGURE 8 – PLOT OF OUTPUT VOLTAGES OF AN ANALOG COMPASS VERSUS DEGREE OF ROTATION

The *Garmin* GPS module was tested for accuracy a couple of ways. First the GPS was placed on a campus survey benchmark and logged for 10 minutes. The values were then compared to the known value of the benchmark. This process was repeated three times on three different days. A second test was performed on the sidewalk by placing the GPS on one side of the sidewalk and collecting data points for ten minutes. The GPS was then moved to the other side of the sidewalk and the center of the sidewalk allowing for ten minutes of data collection at each location. The entire process was repeated three times. The data was then analyzed to determine the sample means, standard deviations, and existence of any outliers. The data was then compared to the other respective sampling locations to determine average distance apart and coordinate overlap.

The RFID system was tested by varying the mounting orientation of the tags and antenna so that the reading range was optimized. It was found that the antenna must be parallel to tag's surface to optimize the reading range. However, the angle relative to the ground did not affect the reading range. So as long as the tag is parallel to the antenna the tag can be mounted in any orientation. During testing it was also found that the RFID tags have two different reading ranges. The tags have a specific range when approached by the antenna. This range was found be approximately six feet. However, the RFID tags had a slightly larger range after the antenna acknowledged them and started to move away. This range was found to be approximately twelve feet.

The robot chassis and motors were tested to determine what types of terrain the robot could potentially handle. A board and a platform were used to determine the maximum incline that the robot could traverse from a dead stop. Twenty degrees was determined to be the maximum incline. Another test was used to determine the maneuverability through different types of terrain. It was found that the robot can navigate on grass, dirt, cement and tile. The robot can drive over any obstacle smaller than 1 ½" thick. Obstacles bigger then this were usually detected by the sensors during testing.

## CONCLUSION

The final design is comprised of a GPS unit, RFID transceiver, UHF antenna, 68HCS12 microcontroller, LPC2148 ARM7 microcontroller, obstacle detection sensors, power supply/interface PCB, and a battery. The *Smart-Robot* design shows promising incentive in improving the lives of visually impaired persons. The ability to go to class, work, or a walk in the park is not an easy task for someone who is visually impaired. Overall, the *Smart-Robot* could make these routine tasks simple and feasible for a visually impaired person.

## REFERENCES


[1] Facts and Figures on Americans with Vision Loss, Internet:http://www.afb.org/Section.asp?SectionID=15&DocumentID=4398, American Foundation for the Blind, New York, NY. 2008.

[2] Information about Vision Loss, Internet: http://www.nfb.org, National Federation for the Blind, Baltimore, MD. 2008.

[3] Guide Dogs, Internet: http://www.guidedogsofamerica.org/faq.html, Guide Dogs of America, Sylmar, CA. 2009

[4] Miniguide, Internet: http://www.gdp-research.com.au/minig_1.htm, Adelaide, Australia. 2009.

[5] Laser Cane, Internet: http://www.noogenesis.com/eta/current.html, Paoli, Pennsylvania. 2009