Smart Walking Cane with Obstacle and Wet Surface Detection Functionalities

Au Khai Xiang, Kwek Wen Lin, Pranesh Balamuniappan

Engineering Science Programme, National University of Singapore

Abstract

In this report, the walking cane for the visually impaired was redesigned. The smart walking cane is capable of obstacle and wet surface sensing to help the visually impaired avoid safety hazards. The obstacle detection is done through a proximity sensor while the wetness detection is implemented through a conductivity sensor. The circuit hardware is housed in an ergonomic mechanical body with its operations are controlled by an Arduino UNO microprocessor. The products' performance is analysed through experiments and user trials from the visually impaired community.

Keywords:
white cane, ultrasonic sensor, conductivity sensor, obstacle detection, wet surface detection, circuit design, Arduino, MATLAB

1. Introduction

Medical technology has been making significant advances of the past few decades. However, the functionality of the walking cane for the visually impaired remains limited. A typical walking cane for the blind is used by swinging it gently from side to side to detect obstacles by feel. This places additional burden on the user by the way one grips the handle when he navigates. Similarly, a blind person on an average day will encounter many different kinds of obstacles, some of which include: street signs, tree branches, fire hydrants and staircases. This becomes a problem as the typical walking cane is unable to detect objects that are raised off the ground. Because of its outdated design, the walking cane is unable to offer the visually handicapped the level of independence that is achievable with modern technology.

In this project, the white cane as a product undergoes redesigning and revisits the product development cycle with an emphasis to discover approaches to give the user more information of the surrounding and thus, help improve their daily commute. The device emits sound waves and picks up the reflections of the waves to warn the user about obstacles. This ability will help aid the visually impaired to navigate its surroundings with ease and reduce travel time. The sonar walking stick will also help to detect objects raised above ground and prevents accidents or injuries from hitting onto those obstacles. A proximity-based vibration feedback system will be implemented to alert user of incoming objects and a wetness sensor was installed at the tip of the walking cane.

In this report, the features of the walking cane prototype such as the mechanical design with drawings will be highlighted and analysis behind the electronics such as the HC-SR04 Ultrasonic sensor and the simulations carried out to test its validity will be thoroughly discussed.

2. Product Overview

Figure 1 gives a first look at the smart walking cane. The cane's functionality is controlled by Arduino software and circuit hardwares. It can be turned on and off at will using a general switch. houses 2 proximity sensors at 50cm and 100cm above ground level. This is to detect objects of different heights, one at knee level the other at waist level. The feedback of the obstacle detection is a vibration motor inside the handle of the cane.

The conductivity sensor is at the tip of the cane to detect wet surfaces. The feedback of the wetness surface detection is relayed by the sound buzzer. Details about the electrical and mechanical aspects of the product design will be discussed in the next sections.

3. Electronic Circuit Design

The functions of the smart walking cane is fundamentally electronic. The two main functions of the smart

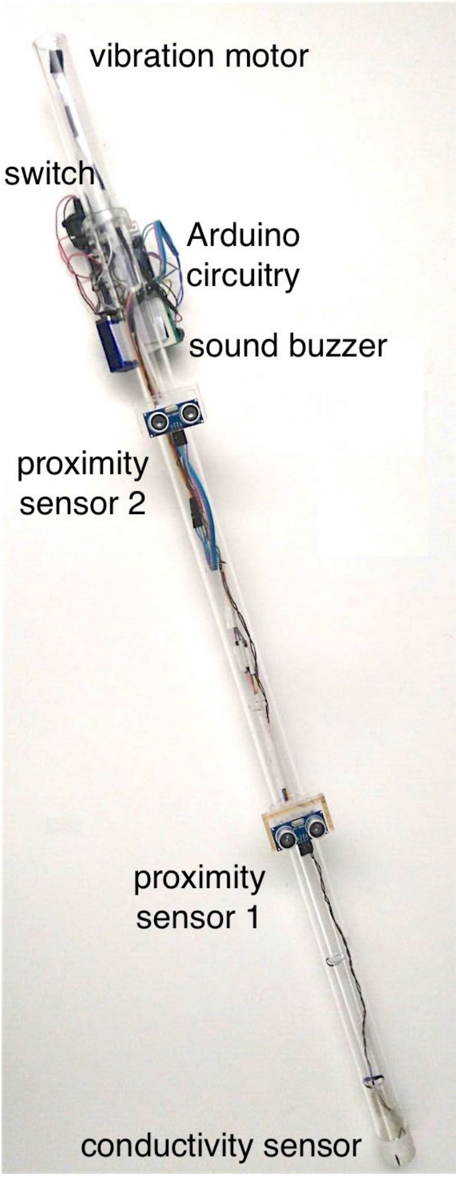

Figure 1: Smart Walking Cane (with labeled parts)

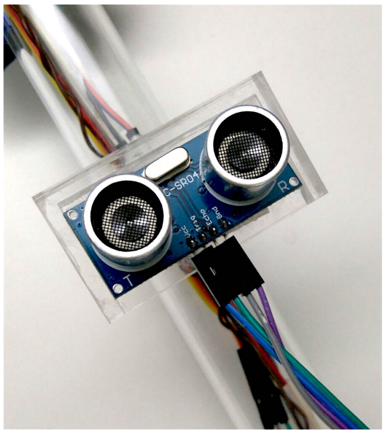

Figure 2: Ultrasonic Transceiver HC-SR04 (housed on a sensor holder)

walking cane is obstacle detection and wet surface detection. Obstacle detection is done using a closed loop system involving an ultrasonic transceiver while wet surface detection is an open loop system through the use of conductivity sensors.

Two circuits operate in parallel to allow both the obstacle sensing and wet surface sensing capabilities. The operations of both circuits are governed by an Arduino UNO that runs on a 9V cell.

3.1. Proximity Sensor

The sonar walking stick is a closed loop feedback system consisting of an ultrasonic transceiver (Figure 2), an Arduino microcontroller and a vibration motor. The ultrasonic transceiver feed input into the system while the output information is relayed to the user through the vibration motor. The Arduino coordinates and controls the system's operation through computer-coded signal processing.

3.1.1. Signal Input

A dedicated getSignal() function (section: Appendix B) is written in Arduino code to collect signal input to determine distance of obstacle. The Arduino sends out a high pulse of 2 microseconds through its pin 13 to the trigger pin of the HC-SR04 ultrasonic transceiver. This prompts the transmitter to send out a series of 8 ultrasonic waves at 40KHz. These sonic waves may undergo reflection, deflection and/or absorption depending on the type of surface it hits.

The Arduino then 'listens' for any signal that returns to the receiver through its echo pin, connected to the Arduino's pin 12. The collection of input is implemented

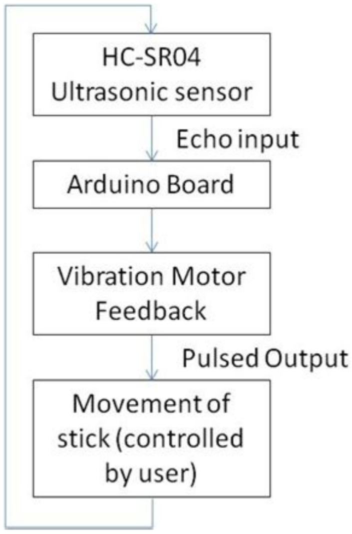

Figure 3: Proximity Sensor Operation Block Diagram

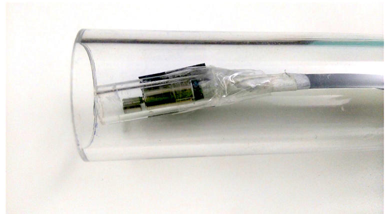

Figure 4: Vibration Motor

Figure 5: Conductivity Sensor at Cane Tip

via the pulseIn() function, which returns the length of a high signal.

$$duration = pulseIn(echoPin, HIGH);$$

The line code assigns to 'duration' the time length in which the signal at the echo pin is high.

3.1.2. Information Processing

The numerical information of signal high's length, named 'duration', is to be processed into a useful representation of the proximity of objects around the user. The equation to convert the signal length (in microseconds) to the object distance (in centimeter) can be derived as such.

$$\begin{aligned} Length &= (speedofsound) * duration \\ &= 343.2(m/s) * duration(us)/2 \\ &= 17160(cm/s) * (duration/1000000)s \\ &= (duration * 0.01716)cm \\ &\approx (duration/58)cm \end{aligned}$$

The factor of 0.5 in the equation shows the true duration of the signal since the wave travels out and then back. The result of the equation is the distance of the object from the sensor in centimeters. Capable of detecting from 3 cm to 4 m, the HC-SR04 transceiver can be used to detect obstacles from a wide range of distances.

For the purpose of the sonar walking stick, the ultrasonic receiver is set to detect a range of 3 to 50 cm. This distance cut-off is acquired from user's respond (7). Objects at further distances are not considered as immediate obstructions in the path of the user and is therefore ignored. Depending on the user's desire, the maximum distance detectable by the sonar walking stick can be calibrated up to an upper bound of 400 cm.

3.1.3. Output and Feedback

After acquiring the distance of the object, the system decide if the obstacle is of any danger. If so, an output is to warn the user of the nearby obstacle. In the Arduino, this is implemented by the giveFeedback() function (section Appendix B). The function takes in the distance measured by the ultrasonic sensor and then compares it to the cut-off's lower and upper bound of 3cm and 50cm respectively. Any signal that falls in between the range qualifies as an obstacle that is nearby.

A high signal is sent through pin 5 of the Arduino which activates the vibration motor (Figure 4). The vibration feedback is felt by the user at the handle. The line of code maps proportionally 'distance' to 'vib' from the range of 20 to 150 cm to the range of 50 to 500 ms. By implementing this output mechanism, the user receives a tactile feedback from the sonar walking stick and is able to respond to the objects in his vicinity.

3.2. Conductivity Sensor

A conductivity sensor (Figure 5) was employed to detect wet surfaces using metal probes. The probes, consisting of metal bolts elevated from the tip by a two nuts,

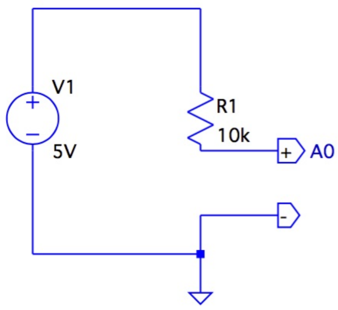

Figure 6: Conductivity Sensor Circuit

comes in contact with rain water or soap water, the conductivity sensor take in conductivity input signal. A wet surface would generate a sound feedback through a buzzer attached near the Arduino board, warning the user of the wet surface.

The choice of metal bolts as probe is due to its low conductivity as well as robustness. The probes have proven experimentally to hold up after continuous usage that causes friction and impact against the ground. The probes are placed 2 cm apart to prevent a false positive response due to liquid cohesion and adhesion between two probe.

3.2.1. Signal Input

The conductivity sensor circuit (Figure 6) is a potential divider. R_1, the fixed resistance is set at $10k\Omega$. The variable resistance R_2 is the measured conductivity of the material probed by the metal bolts. The positive metal probe is connected in series with R_1 and leads to the Arduino's input while the negative probe is grounded.

The probes are placed on the surface desired to checked for wetness. The circuit closes when come into contact with the surface. The probes measure the voltage across the material and the positive probe relays that voltage value into A0 analog input of the Arduino. The measured voltage is mapped proportionally to an integer value from 0 (0V) to 1023 (5V).

3.2.2. Information Processing

The circuit is calibrated with the conductivity of tap water, which measure at an integer value of 900. Tap water is chosen as it is a commonly found liquid on a wet surface. Also, it acts a good lower bound for other impure waters such as salt water and soap water, which have higher conductivity. A material with higher conductivity will yield a lower resistance and therefore a

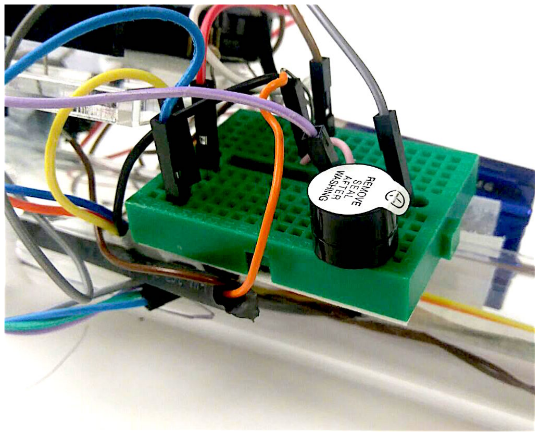

Figure 7: Buzzer

lower voltage reading, i.e. lower than 900. On the other hand, materials with lower conductivity will give a high resistance which translates into a higher voltage reading, i.e. higher than 900. A simple conditional if-else code is used to decide if the probed liquid has higher or lower conductivity than that of tap water. Should its conductivity be lower than tap water (900), the response feedback is activated.

3.2.3. Output and Feedback

To notify a visually impaired persons of the wet surface, a sound buzzer is used. Both project team and users agree that sound response was a good feedback method given the vibration feedback is used by the cane's primary function of obstacle detection.

The sound buzzer (Figure 9) is powered by the Arduino's pin 11 and will create a 'beep' sound to heightened the user's awareness and caution when travelling on wet surfaces.

4. Mechanical Housing Design

The mechanical design of the smart walking cane is integral in making it not only a functional prototype but also a user friendly product. Build using laser cut acrylic, the smart walking cane follows several important product design principles to achieve desired resulting characteristics.

1. Functional
   The cane must never impede the sensors' operations and allow full functionality at all times when in use. Therefore, the cane must be designed to physically contain, support and protect the sensors.

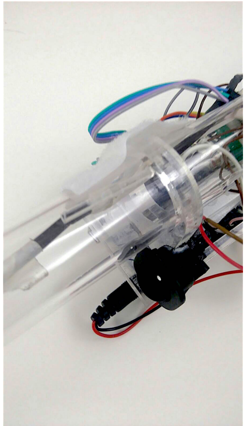

Figure 8: Ridge and Switch

2. Ergonomic
   The cane must provide an enjoyable user experience by being comfortable to hold as well as easy to operate. Moreover, aiming at the visually impaired community the cane must be intuitive enough to be used properly without relying on the sense of sight.
3. Customisable
   Different users give rise to various needs when it comes to configuring the ideal smart walking cane. Therefore the cane should be free and easy to personalise according to the users' requirements or personal preferences. Hence, it is important to design movable parts to allow for variations in configurations.
4. Modular
   As a developing prototype, a modular design is extremely useful to add new product features as well as allow different parts of the product to be used independently. For the smart walking cane, modular parts would enable sensors to be integrated onto users' own canes, thereby removing the cost of purchasing an entirely new product.

4.1. Cane Body

The cane body of the smart walking cane (Figure 1) is made from hard acrylic that was procured in the sensor laboratory. On the outside, a thin ridge was fabricated at the handle of the cane to mark the front of the cane, since the sensor must be used facing forward. The user will adjust his grip along the cane handle until his thumb comes into contact with the ridge.

After gripping the cane, the user can easily turn on the cane using the switch. The switch were positioned such that the user would be able to access them with this index finger without difficulty or ambiguity of the switch's position, making it user friendly. Along the cane body, slots have been drilled at intervals to allow the proximity sensors to be installed at different positions, making is customizable. Users can optimize the right height for the ultrasonic sensor to suit their preferences.

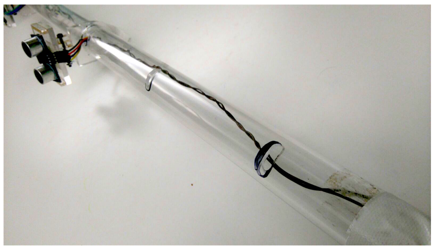

Figure 9: Slots for Proximity Sensor Installation

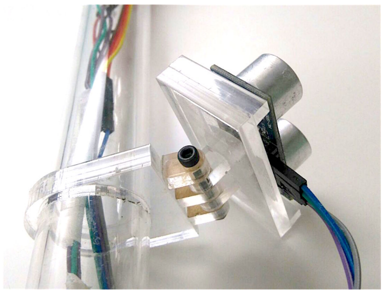

Figure 10: Sensor Holder

A conductivity sensor (Figure 5), which functions as a wetness sensor, was incorporated at the tip of the cane. The tip of the cane usually undergoes the most wear and tear as compared to other parts of the cane, due to the swinging motion. Thus, to ensure the durability of the tip, metal bolts are used as probes. Two nuts elevate the tip of the cane such that the head of the bolts protrude outwards. This ensures the functionality of the probes will not be compromised when the cane is held at an angle.

To improve the ergonomics of the smart cane, the hollow cane body keeps all wires from the ultrasonic sensor and the conductivity sensor circuits neatly shielded from the end user. This was achieved through threading the wires into the hollow internal cavity of the smart cane. The Arduino board used was also situated at the back of the cane so that it would not be interfering the general motion of the user.

4.2. Sensor Holders

The sensor holder (Figures 2 and 10) are built as separate modules for modular design as well as customisability. The sensor holder act as a platform to hold the proximity sensors as well as shield it from impacts from the sides. When installed on the cane body, the sensor holder is designed to move with 3 degrees of freedom:

1. Height level. By sliding the holders up and down the cane, this changes the height at which the proximity sensors are detecting.
2. Vertical axis, or Yaw. By rotating the holders left and right, this changes the lateral direction of the proximity sensors.
3. Transverse axis, or Pitch. By pointing the holders up or down, this changes the angular direction of the proximity sensors.

5. Characterisation

To characterise the smart walking cane, qualitative and quantitative methods have been developed to showcase its accuracy, sensitivity as well as reveal its limits. Knowing the limits of the product enables error margins to be taken into account when performing experiments and analysis.

5.1. Sensitivity towards changes in distance

The smart walking cane is set to detect any obstacles within the range of 50cm and angle of 30-40 degrees. The test was done by placing the object 50cm away and a tester then moves the cane closer to the object gradually. The moment the obstacle is within the range of detection a timer is started. The timer is then stopped when the walking cane vibrates as a sign of successful detection object. Obstacles test included static objects such as walls, tables, furniture and moving objects such as people and rolling chairs.

The cane recorded an immediate response when obstacles fall within range of detection. The recorded time was 250-300ms. Taking into account the reaction time of the user to stop the timer, the estimated lag time between detection and vibration feedback is approximately 100-150ms. This speed of response is sufficient for the user to respond to any nearby obstacle after being notified by the vibration feedback.

5.2. Response towards angled surfaces

The cane is placed perpendicular in front of a wall. The vibration feedback is activated. The cane is then tilted gradually away from the wall. The angle subtended by the wall and the ultrasonic sensor is recorded when the vibration feedback stopped reacting. The resultant angle is 40 degrees.

Figure 11: Basement

This signifies the physical limitations of ultrasonic sensor. Any surface that is angled away too much, more than 40 degrees, from the transmitter will not reflect the waves back to the receiver of the sensor. Therefore, no reading is received and the stick assumes no obstacles to be in vicinity. This is the blind spot and weakness of the product.

6. Experiment

To test the performance of the smart walking cane, the smart walking cane is tasked with mapping its environment using its proximity sensors. Similar to the operations of radar, the smart walking cane's quality will be judged on how well it represents its vicinity. The experiment is held at two locations, chosen to represent both indoors and outdoors obstacles such as table, chair, bins, walls and ledges. Below are the experiment's procedure:

1. The cane is swung 180 degrees from left to right.
2. For every 10 degrees of directional change, the top sensor's reading is collected.
3. For every 10 degrees of directional change, the linear distance from sensor to nearest obstacle is measured using a measuring tape.
4. Taking into account the sensor's allowance of at an lower estimate of 30 degrees, the linear distance measurements are modified to reflect a 30 degrees allowance as well.
5. Sensor readings, linear distance measurements, and modified linear distance measurements are plotted on the same graph in MATLAB for visual comparison.
6. The Euclidean norm between the sets of data is taken to quantify the error of the sensor readings.
7. Steps 1 to 6 are repeated for the bottom sensor.

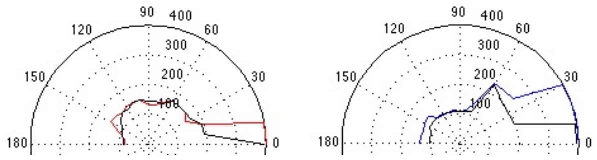

Figure 12: Polar Plot of Sensor Reading against True Distance (Basement)

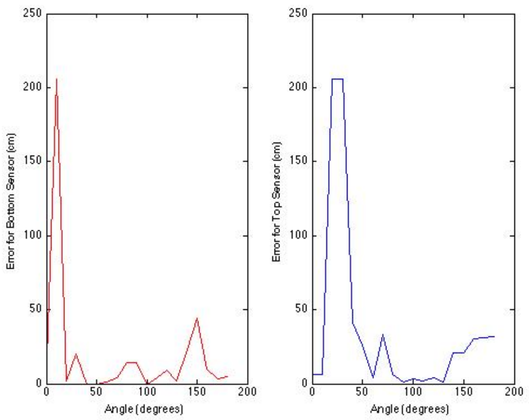

Figure 13: Plot of Distance Error against Angle (Basement)

6.1. Basement of Tembusu College

As seen in figure 11, on the left there is a ledge about knee level. In front there is a long table, two large trash bins and three recycle bins. On the right is a hallway.

6.1.1. Results and Analysis

In figure 12, the black lines in the polar plot represent the true distances while the red and blue lines represent the bottom and top sensors respectively.

1. 0 - 15 degrees
   Both sensors record the hallway, therefore a high distance of more than 3 meters.
2. 15 - 30 degrees
   The bottom sensor (red) is reading consistently less than the top sensor (blue). This correspond to the recycle bins, where the bottom sensor sense the bin while the top sensor sense the wall above it.
3. 30 - 90 degrees
   Both sensors record the large trash bins at the same distance, about 1 m.
4. 90 - 150 degrees
   It can be seen that the bottom sensor (red) is reading consistently 50cm more than the top sensor (blue). This coincide with the table, where the top sensor senses the tabletop while the bottom sensor senses only objects behind the table.
5. 150 to 180 degrees
   The top sensor consistently records more than top sensor. This is because the ledge (for sitting) has no obstacles above it while the bottom sensor records the ledge itself, which is close by.This is consistent with the shape of the environment and expected results.

Figure 14: Corridor

Looking at the error plot, a sharp error occurs at 20 degrees to 30 degrees, where the wall ends and the hallway begins. This difference in sensor reading and measured distance can be observed at the polar plots as well. While the true distance at 20 degrees may be 1m, the sensor may already begin recording the hallways distance instead which is much further at 3m and more. A similar effect at 150 degrees is observed for the bottom sensor. This is the intersection between the ledge and the table area. While the bottom sensor is pointing towards the ledge, it has already started sensing the bottom of the table, giving a higher distance reading.

Overall, the agreement between the two error plots show that it is a systematic error that affects the sensors' performance. This error is due to the 40 degree allowance of the ultrasonic sensor. Such errors occur when there is a sudden change in distance and the sensor may not immediately discern the new environment, the smart walking cane's proximity sensors perform well at detecting different obstacles.

Using the cosine similarity method (which takes the L2 norm, or Euclidean norm between the sensor data and the true distance data), the top sensor shows an accuracy of 96.36% while the bottom sensor shows an accuracy of 96.79%.

6.2. Corridor in Tembusu College

Following figure 14, on the left there is a wall. In front there is a chair, a ledge with bags on it, a waste paper basket and on the top right leads to a corridor. Lastly direct on the right is another wall. The experiment is repeated at the corridor as it was at the basement.

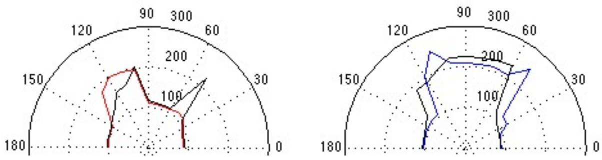

Figure 15: Polar Plot of Sensor Reading against True Distance (Corridor)

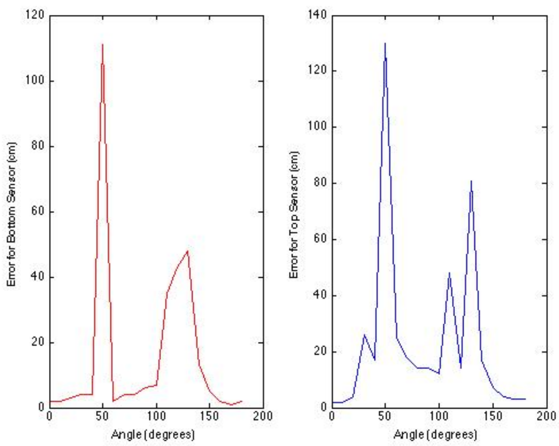

Figure 16: Plot of Distance Error against Angle (Corridor)

6.2.1. Results and Analysis

1. 0 - 30 degrees
   Both sensors record the wall on the right at about 90cm.
2. 30- 60 degrees
   The bottom sensor (red) is reading 30-40cm consistently less than the top sensor (blue). This correspond to the waste paper basket, where the bottom sensor sense the bin while the top sensor sense the corridor behind it.
3. 60 - 100 degrees
   The bottom sensor consistently reads 1.2m less than the top sensor. This is because there is a ledge where the bottom sensor senses the near end of the ledge while the top sensor only senses the far end of it.
4. 90 - 140 degrees
   It can be seen that the bottom sensor (red) is reading consistently 1m more than the top sensor (blue). This coincide with the chair, where the top sensor senses the chair's seat while the bottom sensor senses only the wall behind it.
5. 140 to 180 degrees
   Both sensors detect the wall on the left at about 1m.

Looking at the error plot, a sharp error occurs at 50 degrees, where lies the intersection between the wall on the top right corner of the live picture and the corridor. For the top sensor, while the true distance at 50 degrees is at the wall, the top sensor has sensed the deepest end of corridor detectable, which is at a much further distance at 2m. As for the bottom sensor, at 50 degrees though the true distance is the wall behind the waste paper basket, the bottom sensor already started detecting the waste paper basket. It fails to detect the wall as its signals from the waste paper basket overpowers the weaker signal from the walls.

At 130 to 140 degrees, another peak in the error plot is observed. This is the intersection between the chair and the wall behind it. For the bottom sensor, while the true distance is that of the wall on the left, the sensor reads the wall behind the chair at a much greater distance. For the top sensor however, the true distance of the wall behind the chair is misread as the distance of the chair itself, resulting in a much lower distance.

Similar to the case in the experiment at the basement, the agreement between the two error plots show that it is a systematic error that affects the sensors' performance. This error is due to the 40 degree allowance of the ultrasonic sensor. Other than errors at areas of sharp changes in distance or changes within a small angular range, the smart walking cane's proximity sensors perform well at detecting different obstacles.

Using the cosine similarity method the top sensor shows an accuracy of 97.13% while the bottom sensor shows an accuracy of 97.15%.

The experimental errors are parallax errors when reading measuring tape, parallax errors when pointing sensor at correct angles and systematic errors of sensor due to its limitations, i.e. 40 degrees allowance.

7. User Feedback

Overview

Insightful feedback and positive support was received from members of the visually handicapped like Dialogue in the Dark. The guide who met with the project tea was Elaine. Elaine is a member of the Dialogue in the Dark from Ngee Ann Polytechnic, she was born with partial sight and was brought up and learn to use the walking cane. Her blindness has worsen when she aged, she has grown comfortable with using the walking cane. During the visit to the exhibit, our sense of sight was withdrawn in a familiar environment and the smart walking cane concurrently tested.

One of the key factors noted was the long learning curve it takes for the blind user to use the walking cane, this is important because a seasoned walking cane user may pose a challenge in trying to integrate new sensor technology to accommodate their needs. Similarly, more effort needs to be done in trying to understand the real problem blind users face in their daily life.

The ergonomics of the walking cane also plays an important role for the user, such as weight and feel of the stick. Ideally, the length of the stick should be at the chest level and the bottom contact should be rounded to prevent wear and tear damage. In the near future, more resources will be allocated to improve on the design of the device.

Functionality of the walking cane was also put into question, areas such as the vibration feedback intensity needs to be set at a level where it shall not be an annoyance to the user's hands. Special attention needs to paid towards the angle of the ultrasonic sensor because incoming objects towards the user above chest-level cannot be detected easily. All of this, factoring in the personal preference of the individual will play an vital role in the design of the walking cane to ensure mass adoption like the commercial available hearing aid for instance.

Dialogue in the Dark was also kind enough to provide a written statement of support for the smart walking cane. The statement can be found at Appendix F.

7.1. Interview

Below is a brief summary of the interview and Elaine's responses.

1. How does it feel to use the walking cane?
   It takes a long learning curve to use the walking cane, much as learning to drive a car. I learnt to use the walking cane from young and adopted to it with my sight limitations
2. What are your thoughts on using technology to improve on the walking cane?
   A lot of things need to be factored, such as the ergonomics of the cane like weight and the feedback system needs to be well optimized for the user. Think about the hearing aid that was widely adopted in the market, can your product reach that level of integration into the blind user?

After using the sonar walking cane, a second round of questioning was held to collect her feedback about her product experience.

1. What do you think of the cane in terms of ergonomics?
   The prototype is heavy and needs improvement, as for the height it needs to at the chest level like the standard walking cane. The bottom-contact can be improved with a round-tip to protect the cane from constant abrasion from swinging.
2. Do you like the vibration feedback?
   The vibration feels to be a slight annoyance to my handgrip; sometimes we need obstacles during our outdoor travel as they serve as useful landmarks for navigation. If possible, it will be great if we have a choice to turn off the vibration if possible. I will prefer a softer vibration on my grip.
3. Where do you think the proximity sensors will be useful?
   As for the sensor useful for detecting objects above ground, based on my individual preference, I navigate raised objects by holding my cane close to her body at a 45 degree angle. I am used to that when I am navigating say indoors like my house or working place. However for objects above waist, it will be great to be sensors placed there as they are hard to reach.
4. Do you think the wetness sensor fulfils its purpose?
   It will be great if the probes are designed such that it can detect wet surfaces at an angle, I see the potential in that when I want to avoid those areas. The sound for buzzer itself is good enough for me.

At the end of the meeting, Elaine gave some concluding thoughts on the product, factoring the constraints and budget.

1. Do you think this product will give users the confidence to navigate?
   That is hard to say in my perspective because I feel that the vibration feedback will be a distraction to my experience in learning to use it.
2. Do you see the potential use case for this obstacle avoidance system in hazardous environments?
   I see the possibility in that, but the sensor feedback needs to be closer. There are times when I come into contact with hanging tree branches and pillars on the sides, so it will be great if there are sensors that tell you that.
3. What are you general thoughts on the future improvements/applications?
   I appreciate your thought and effort in trying to fabricate this sonar walking cane for us, but I feel that more effort needs to be done innovators to try and understand the real needs of the blind before they design the product. If possible, an idea I have for you will be to try and install cameras on the cane to that detects objects and informs the user about it or an audio feedback GPS tracker to an app? That

will help me greatly in navigating important landmarks and reduce my travel time.

7.2. Modifications

Based on the feedback from Elaine as well as the interns at Dialogue In The Dark, many modifications have been made to the smart walking cane. Notable changes made to the product are

1. Repositioning of top sensor at waist level to detect object of higher level.
2. Installation of a general switch near handle so that the vibration feedback may be disable and enabled at will.
3. Weakening of vibration strength to suit the user's preference. Further personalisation is achieved through code.
4. Increase in probe length for use at wider angles. This rids of the initial shortcoming of the cane being useful only when held perpendicular with the floor.
5. Rubber grip added at the handle for comfort of user's hand when grabbing onto cane handle.

However, concerns regarding ergonomics and added functionalities are not achievable within the time and budget given for the design project. Therefore, they are left as future work and improvements.

8. Future Work

Several changes can be considered for future improvements.

1. Dedicated Integrated Circuit
   To fully miniaturised the circuitry of the smart walking cane, the Arduino microprocessor has to be eliminated. This can be done by developing a dedicated integrated circuit to control the proximity and conductivity sensors. The integrated circuit chip and the entirety of its circuitry may then fully be concealed within the walking cane, leaving it hazard-free on the outside.
2. Improved Ergonomics
   By increasing funding, a professional made cane will be made to the correct length and thickness, with the right material that is light and durable. This will overall improve the product and match up against existing commercial walking canes.

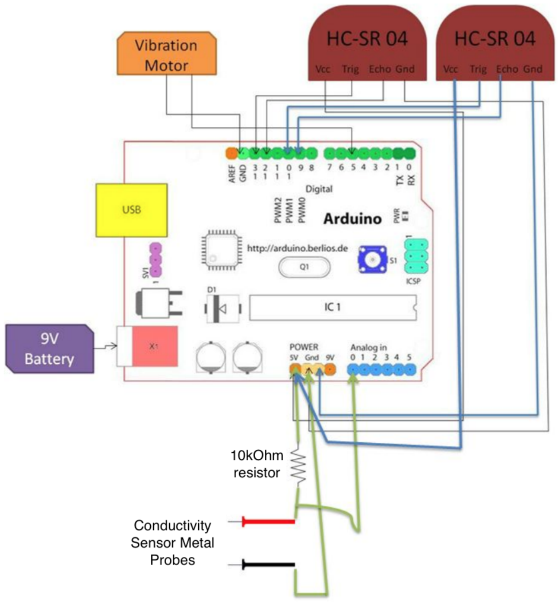

Figure A.17: Arduino Circuit Block Diagram

3. Additional Features - Bus Number Identification
   Several methods may be explored to enable bus number identification or other similar functions. One method is to use RFID signals transmitted from the bus to the cane. The cane will then respond to the user through a sound respond.

9. Conclusion

In conclusion, The smart walking cane achieves its function with great accuracy as shown by experimental results. However, it still falls short in product ergonomics due to the insufficient production value of the project. Therefore, with more funding and expertise, the smart walking cane can become a truly useful product that aids the quality of life of the visually impaired community.

Appendix A. Circuit Block Diagram

Appendix B. Arduino Code

```
//This code governs the operation of the
    proximity sensor

#define trigPin1 10
#define echoPin1 9
#define trigPin2 13
```

```
#define echoPin2 12
#define vibPin1 5
#define buzzer 11
#define wetnessProbe A0

  long duration, distance, duration2,
      distance2;
  int maxDistance = 30;
  int minDistance = 5;
  int wetness;

void setup()
{
  Serial.begin (9600);
  pinMode(trigPin1, OUTPUT);
  pinMode(echoPin1, INPUT);
  pinMode(vibPin1, OUTPUT);
  pinMode(trigPin2, OUTPUT);
  pinMode(echoPin2, INPUT);
  pinMode(buzzer, OUTPUT);
}

void getSignal (int trigPin, int echoPin, int
    trigPinb, int echoPinb)
{
  //sends a high signal to the TRIGGER pin
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  //calculation of distance from signal
      duration
  duration = pulseIn(echoPin, HIGH);
  distance = duration/58;

  //repeat same process for sensor 2
  digitalWrite(trigPinb, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPinb, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPinb, LOW);

  duration2 = pulseIn(echoPinb, HIGH);
  distance2 = duration2/58;
 }

//this functions collects input from HC-SR04
void giveFeedback (int vibPin)
{
  //decide if distance is within range
  if ((distance >= minDistance && distance <=
      maxDistance) || (distance2 >=
      minDistance && distance2 <=
      maxDistance))
  {
    //activate vibrator
    analogWrite(vibPin, 255);
  }
  //disable vibrator
  else analogWrite(vibPin, 0);
 }

//this functions operates the conductivity
    sensor
void wetnessTest ()
{
  //read voltage from metal probes
  wetness = analogRead(wetnessProbe);

  if (wetness <= 900)
  {
    //sound buzzer if conductivity is high
    digitalWrite(buzzer,HIGH);
  }

  else
  {
    //disable buzzer if conductivity is low
    digitalWrite(buzzer,LOW);
  }
 }

void loop()
{
  getSignal (trigPin1, echoPin1, trigPin2,
      echoPin2);

  //display readings on serial monitor
  Serial.print(distance);
  Serial.print("            ");
  Serial.print(distance2);
  Serial.println("");

  giveFeedback (vibPin1);
  wetnessTest();
}
```

Appendix C. Drawings for Mechanical Parts

Appendix D. Experiment Data

```
//bottom sensor reading at corridor
s1corridor
    =[101;102;102;104;130;180;202;200;...
196;110;108;108;110;115;112;95;89;88;88];

//bottom sensor measurement at corridor
```

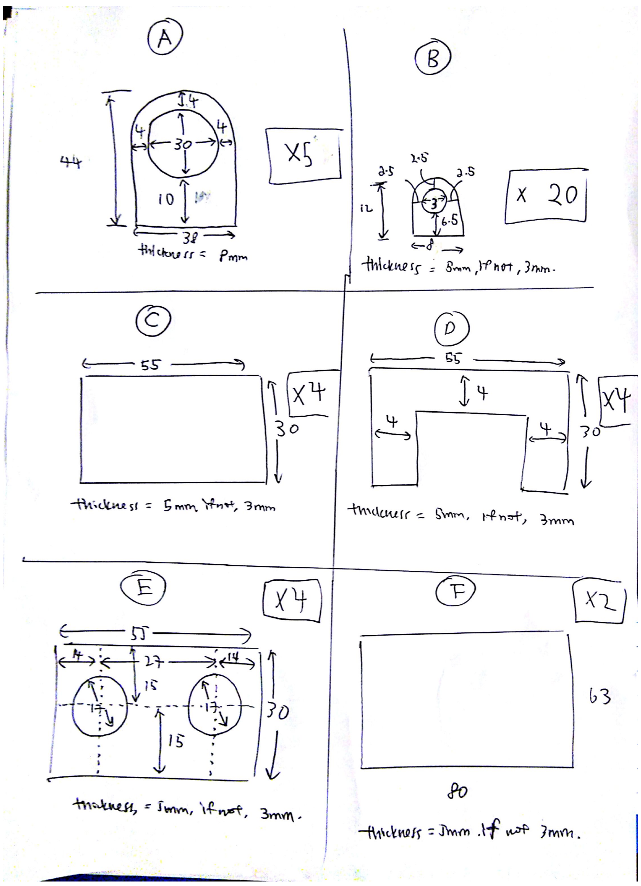

Figure C.18: Drawings for Laser Cutting

```
m1corridor
    =[109;110;115;123;138;165;171;225;...
212;209;122;118;232;262;303;114;105;98;96];

//top sensor reading at corridor
s2corridor
    =[103;103;104;105;106;105;200;252;...
212;210;210;212;210;250;121;121;94;90;90];

//top sensor measurement at corridor
m2corridor
    =[112;114;118;129;310;192;210;282;...
230;230;236;254;241;262;126;110;101;96;94];

//top sensor reading at basement
s2basement
    =[136;135;134;140;140;116;112;112;...
113;111;116;150;234;234;235;400;400;400;400];

//top sensor measurement at basement
m2basement
    =[110;110;135;125;130;128;123;122;...
116;116;123;236;242;245;214;200;400;400;400];

//bottom sensor reading at basement
s1basement =[79;81;103;147;145;138;145;147;...
150;132;132;150;165;166;166;148;196;400;400];

//bottom sensor reading at basement
m1basement =[90;99;109;128;150;142;157;167;...
166;156;152;175;185;172;174;220;200;400;400];
```

Appendix E. MATLAB code

```
%% This function graphs the sensor reading
    against the true distance measurements in
    a polar plot. The error is calculated and
    plotted as well. Lastly it calculates the
    similarity between two vectors: sensor
    reading and true distance.

function [sim1 sim2] = proxSensor(s1,s2,m1,m2)

% 1 = bottom sensor
% 2 = top sensor
% length of vector = 19
angle = pi:-pi/18:0;

% 6cm offset to account to sensor distance
    from cane
m1 = m1 - 6;
m2 = m2 - 6;

m1mod = dataMod(m1,3);
```

```
m2mod = dataMod(m2,3);
err1 = abs(s1-m1mod);
err2 = abs(s2-m2mod);

sim1 = dot(s1,m1mod)/norm(s1)/norm(m1mod);
sim2 = dot(s2,m2mod)/norm(s2)/norm(m2mod);

close all;

%error plot
figure;
subplot(1,2,1);
plot(angle*180/pi,err1,'r');
xlabel('Angle (degrees)');
ylabel('Error for Bottom Sensor (cm)');
subplot(1,2,2);
plot(angle*180/pi,err2,'b');
xlabel('Angle (degrees)');
ylabel('Error for Top Sensor (cm)');


figure;
subplot(1,2,1);
polar(angle,s1','r');
hold on;
polar(angle,m1mod','k');
subplot(1,2,2);
polar(angle,s2','b');
hold on;
polar(angle,m2mod','k');

end
```

```
%% This function takes in a vector, an
    outputs a new vector where each entries
    is the lowest value chosen from itself,
    its left neighbour and its right
    neighbour. This accounts for a 30 degrees
    allowance for the sensor.

function [y] = dataMod(x,s)

%s for spread
%ls for left spread
N = length(x);
y = zeros(N,1);
temp = zeros(s,1);

if mod(s,2) == 0 %spread is even, left is 1
    more than right
   ls = -(s/2);
else %spread is odd
   ls = -floor(s/2);
end
for i = 1:N

    for k = 0:s-1

        if (i+ls+k) <= 0
            temp(k+1) = 9999;

        elseif (i+ls+k) > N
            temp(k+1) = 9999;

        else
            temp(k+1) = x(i+ls+k);
        end

    end

    y(i) = min(temp);

end
```

Appendix F. Statement of Support

I think the overall idea of having this cane may be beneficial to people with a certain degree of visual impairment. It may not benefit me as much because the height and weight of the machine is not suitable for me. Moreover, the machine sends vibration when it detects something, but it may distract the user, especially if they are focusing on their surroundings. I feel that the vibration function should be adjustable according to the user's preference. If the cane can detect something above stomach level, it will ensure the safety of the user even more. I suggest more research about the target audience, visual impairment and practicality to be done.

- Elaine, visually-impaired guide

We feel that the smart cane is a good idea to have. There may be many faults since it is still at the initial stage of implementation. We feel that with more funding and research, the cane will become a product beneficial to the visually-impaired community.

- Interns, Dialogue in the Dark

Acknowledgment

The authors would like to thank Professor Anjam Khursheed, Professor Ernest Chua and Professor Raisul Islam for their advisory roles that provide constant guidance and constructive criticism throughout the project thus far. The authors also extend their gratitude towards Mr. Karrupiah for aiding the completion of the prototype through hands-on technical assistance in the laboratory.

References

[1] Bahadir, S. K., Koncar, V., & Kalaoglu, F. (2012). *Wearable obstacle detection system fully integrated to textile structures for visually impaired people*. Sensors & Actuators: A. Physical, 179, 297.

[2] Bay Advanced Technologies. (n.d.). *BAT "K" sonar: Ultrasonic sensing device for the blind*. Retrieved April 20, 2012, from `http://www.batforblind.co.nz`

[3] Eric, T. (2008). *Infrared vs. ultrasonic ? What you should know*. Retrieved April 20, 2012, from `http://www.societyofrobots.com/member_tutorials/node/71`

[4] Garg, A., Balakrishnan, M., Paul, K., Paul, R., Mehra, D., Singh, V., Manocha, D. (2007). *Cane mounted knee-above obstacle detection and warning system for the visually impaired. In Proceedings of the 11th International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (pp. 143-151). New York, NY: American Society of Mechanical Engineers.*

[5] Guerrero, L. A., Vasquez, F., & Ochoa, S. F. (2012). *An indoor navigation system for the visually impaired.* Sensors, 12(6), 8236-8258

[6] Levesque, V. (2005). *Blindness, technology and haptics* (Technical Report, No. TR-CIM-05.08). Montral, Canada: McGill University.

[7] Roentgen, U. R., Gelderblom, G. J., Soede, M., & de Witte, L. (2008). *Inventory of electronic mobility aids for persons with visual impairments: A literature review. Journal of Visual Impairment and Blindness, 102(11), 702-724.*

[8] Ulrich, I., & Borenstein, J. (2001). *The GuideCane: Applying mobile robot technologies to assist the visually impaired.* IEEE Transactions on Systems, Man, and Cybernetics, 31(2), 131-136.