THE ECHO BELT:

NAVIGATION TECHNOLOGY FOR THE VISUALLY IMPAIRED

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The Echo Belt: Navigation Technology for the Visually Impaired

Abstract

For many people suffering from vision loss, travelling on foot can be stressful and requires the use of a navigational tool, such as the white cane or guide dog. However, these current aid devices only operate in a single direction, must be held in hand, and can be intrusive to others. The goal of this project was to design, develop and program a discrete, non-intrusive and hands-free navigation device for the visually impaired to reduce the stress related to travelling and, therefore, improve their quality of life. If the device featured ultrasonic technology and vibration motors implemented into a belt, then users could accurately determine the direction and, after a brief training exercise, the distance of obstacles around them. After initial prototyping and testing on a breadboard, small improvements and changes were made to the design. The final product was developed using the Arduino Nano V3.0 micro-controller, HC-SR04 ultrasonic sensors, and 10mm vibration motors, all soldered into a permanent circuit. The device was programmed in the Arduino Software IDE. During product testing, users were blindfolded and asked to locate obstacles placed around before and after receiving training on for the device. As a result, their ability to determine an obstacles direction and distance improved after participating in the brief 5-minute training exercise. The Echo Belt succeeds in providing those with visual impairments a discrete, non-intrusive and hands-free navigational tool, which will make travelling on foot less stressful and overall improve their quality of life.

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Introduction

Travelling by foot makes up a large portion of a person's life. Whether it is travelling to your workplace, or simply taking a walk in the park to relax, the ability to freely go anywhere is essential in maintaining a person's quality of life. For someone suffering from vision loss, however, the action of walking a couple of blocks to get groceries can be a very stressful one that requires preparation beforehand. Current navigation tools for the visually impaired have limited functionality, require extensive training, can be intrusive to others, and puts the user at risk of being targeted. Furthermore, those suffering from less severe vision loss, who feel their partial vision does not warrant the use of current navigation devices, do not have a discrete alternative to use.

Question

In what way could ultrasonic sensing and directional haptic feedback be implemented into a novel navigational device to provide a discrete and hands-free alternative solution for the visually impaired?

Purpose

The objective of this project was to design, develop and program a discrete, non-intrusive and hands-free navigation device for the visually impaired to reduce the stress related to travelling on foot, and therefore, improve their quality of life.

Hypothesis

If a navigational device for the visually impaired which features ultrasonic technology and vibration motors is constructed into a belt, then users' ability to accurately determine the direction and distance of obstacles would improve after a brief training exercise. This is because there are touch receptors all throughout the body, including the stomach and back, and the vibration motors provide precise haptic feedback by varying their strength based on the distance of the obstacles.

Background

Visual impairment or low vision is a severe reduction in vision that cannot be corrected with standard glasses and reduces a person's ability to function at certain or all tasks. The World Health Organization (WHO) defines impaired vision in five categories:

- Low vision 1 is a best corrected visual acuity of 20/70.
- Low vision 2 starts at 20/200.
- Blindness 3 is below 20/400.
- Blindness 4 is worse than 5/300
- Blindness 5 is no light perception at all.

A visual field between 5° and 10° (compared with a normal visual field of about 120°) goes into category 3; less than 5° into category 4, even if the tiny spot of central vision is perfect.

The visually impaired makes up a large portion of Canada's population. There are approximately half a million Canadians living with significant vision loss, and 5.5 million more with a major eye disease that could cause visual impairment. Other factors leading to a dramatic increase of the number of people with sight problems in Canada includes a doubling of the senior population (65 years and older) in the next 25 years and a growing incidence of key underlying causes of vision loss, such as obesity and diabetes. In Canada the largest agency serving blind and visually impaired persons is The Canadian National Institute for the Blind (CNIB)

There are roughly four major causes of blindness and visual impairment in Canada: macular degeneration, diabetic retinopathy, glaucoma and cataracts. The remaining causes are from various diseases, genetic predispositions and accidents.

Macular Degeneration

The macula is a small spot near the centre of the retina. This area is responsible for control of colour vision. If the macula deteriorates, the centre of the person's field of vision becomes blurred, and the ability to read is lost. Macular degeneration seems to be part of the normal aging process.

Diabetic Retinopathy

The retina contains the light-sensitive nerve cells and fibres that transmit images to the brain. It is nourished by a network of blood vessels. In some diabetics, these fine blood vessels become more fragile and likely to bleed, causing loss of sight.

Glaucoma

Glaucoma is an eye disease associated with abnormal pressure in the eye causing degeneration of the optic disk and may restrict in the field of vision.

Cataracts

A cataract is a clouding of the crystalline lens of the eye. The purpose of the lens is to bring the light rays entering the eye to a focus on the retina. When the lens becomes cloudy, the light rays cannot get through and the person loses sight. The only treatment for a cataract is surgical removal of the lens and replacement by an artificial lens.

Blindness and visual impairment should not restrict a person from living a full life. Many blind persons have productive careers, attend school and universities and participate in recreational activities. On the other hand, there are many blind and visually impaired Canadians who have not been as successful in their adaptation and who require extensive rehabilitation and social services. About half of Canadian working-age adults with vision loss make $20,000 a year or less. Also, the visually impaired are at greater risk of social isolation and reduced community participation. They live with an overall lower quality of life compared to Canadians with normal vision.

Current Solutions

The two most commonly used navigational devices for the visually impaired are the white cane and guide dog.

White Cane: The cane is used to check for objects in a person's path, changes in the walking surface (from cement to grass, for example) and to check for dangers like steps and curbs. A secondary function is identification: recognized around the world, the white cane clearly tells other pedestrians and drivers that the user is a person with vision loss. All types of white canes require special training from an Orientation and Mobility instructor, who demonstrates proper techniques, wayfinding and safety.

Guide Dog: The animal has been taught to respond to commands from the owner, such as "Forward", "Left", "Right" and "Straight on". The owner is responsible for daily care and veterinary costs. They are usually paired with the dog for about 8 years. Also, it is easily recognizable by the white harness and requires about a month of training period with the new owner.

While both of these devices enable those with visual impairment to travel independently, they suffer from some basic limitations: they only provide obstacle feedback in a single direction at any given time, they require the use of at least one hand, and they can be intrusive to pedestrians. They also make the user easily identifiable as visually impaired, which is important for other pedestrians, but also makes them targets of crime. The rate of serious violent crime for persons with disabilities (12.7 per 1,000) was more than three times the rate for persons without disabilities (3.9 per 1,000) in 2010 to 2014. The main reasons why those with less significant vision loss don't tend to use devices such as the white cane or guide dog are because they don't want others to know they are suffering from vision loss and feel they aren't "blind enough" to warrant their use.

Bats use echolocation to find and identify objects in their surroundings. Ultrasonic sensors operate under the same principles, by measuring the elapsed time from emitting a sound wave to receiving it. Using this time and the speed of sound through air (344m/s), the distance of an object can be calculated. Only one ultrasonic sensor can be running at a time, since the sensors send the same wave frequency and would interfere with each other. And if the sensor is moving too much, or the surface it is trying to detect is angled, then the emitted sound wave might not return to the sensor.

Design and Procedure

Materials

- Arduino Uno
- Arduino Nano V3.0
- 6 x Ultrasonic Sensor (HC-SR04)
- 6 x Mini Vibration Motor - 10mm
- 6 x Diode
- 6 x NPN Transistor (PN2222)
- 6 x Resistor (1K Ω)
- Jumper Wire
- Breadboard
- Wire Cutters
- Soldering Iron
- Solder
- Electrical Tape
- PCB Board
- Plastic Battery Storage Case (4 x AA)
- Multimeter
- 28 AWG Copper Electrical Wire (Several colours)
- Belt
- Velcro
- Needle and thread

Building the prototype

Step 1 - Stripped the ends of two female jumper wires and 28AWG copper wire (yellow).

Step 2 - Spliced the ends of the jumper wires and the copper wire together and soldered at the joint. Wrapped the exposed wire with electrical tape.

Step 3 - Stripped the ends of two more female jumper wires and two copper wires (black and red).

Step 4 - Spliced one jumper wire to the black wire, and the other to the red wire. Soldered and wrapped electrical tape at the joint.

Step 5 - Repeated steps 1-4 until I had six of each connection.

Step 6 - Connected jumper wires to the proper pins on the ultrasonic sensors (yellow to Trig+Echo, black to Gnd, and red to Vcc).

Step 7 - Stripped and soldered the 28AWG copper wire ends to the Arduino Nano (yellow to pins D2, D4, D7, D8, D12, and D13, red to 5V, and black to GND).

Step 8 - Stripped, spliced, and soldered the positive end (red) and negative end (blue) of the vibration motors to their matching copper wires (red and blue). Wrapped the exposed wire with electrical tape.

Step 9 - Placed the NPN transistor, 1k resistor, diode, and ends of the vibration motor wire in the PCB board. Created five more of these modules.

Step 10 - Soldered all of the electrical components into the board.

Step 11 - Connected the modules to power by soldering the red wire from the battery holder to the board and used solder to connect it throughout the board.

Step 12 - Connected all grounds together (from sensors, circuit board, battery holder, and Nano) on the board by soldering them together (used black copper wire if necessary).

Step 13 - Used yellow copper wire to solder the 6 motors (from 1K resistor) to PWM pins D3, D5, D6, D9, D10, and D11)

Step 14 - Stripped and solder red copper wire to connect + power from battery holder to Vin pin on Nano.

Step 14 - Sewed circuit board to belt with needle and thread.

Step 15 - Attached battery holder beside the circuit board using Velcro.

Step 16 - Attached 6 ultrasonic sensors spaced around the belt using electrical tape (3 front, 3 back).

Step 17 - Attached 6 vibration motors on the inside of the belt, same location as the sensors (peel away paper and stick).

Step 18 - Clean up excess wire with electrical tape.

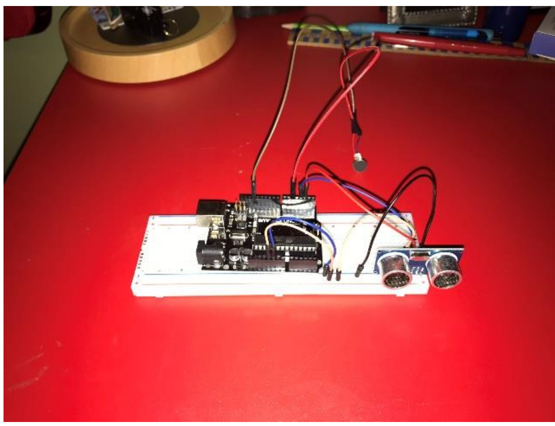


Figure 1 - First prototype

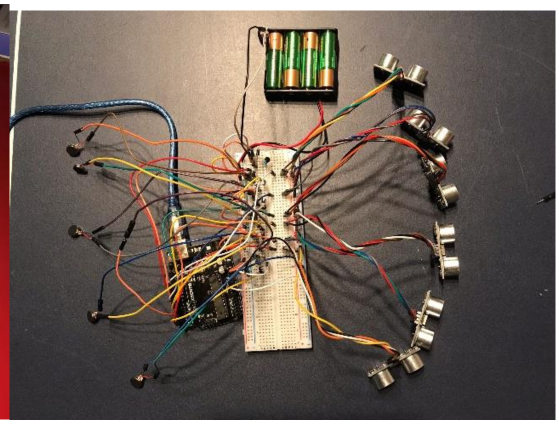


Figure 2 - Final design on breadboard

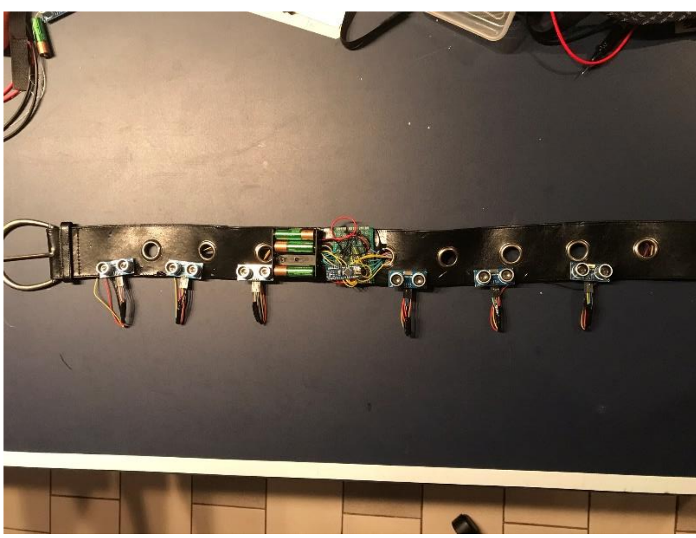


Figure 3 - Outside of belt

Figure 4 - My makeshift soldering station

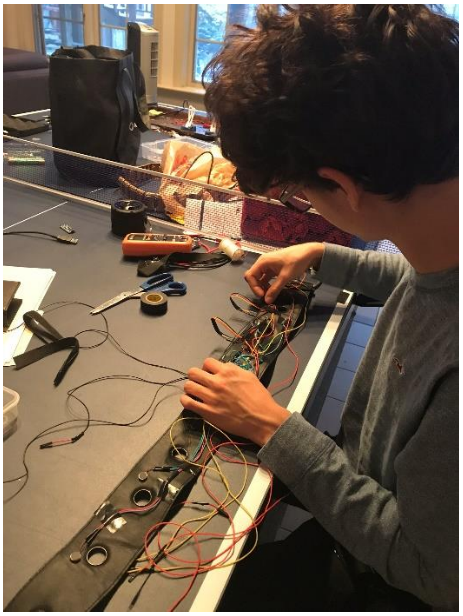


Figure 5 – Organizing the wires

Product Testing

1. Using masking tape, an "X" was marked on the floor, with the area around it cleared.
2. Dashes of masking tape were stuck in front of each of the 6 ultrasonic sensors, at distances of 0.5m, 1.0m, and 1.5m.
3. Participants were asked to put on the device and stand on a marked spot.
4. Participants were then blindfolded
5. Music was played in the background to allow objects to be places without giving sound.
6. Participants counted down from ten while an obstacle was placed, using a predetermined list, somewhere on one of the pieces of tape.
7. The participant guessed the direction (e.g. front left) and the distance of the obstacle.
8. The participant's guess is recorded.

9. Steps 6-8 were repeated nine times, each using a different obstacle direction and distance.

10. Participants then went through a brief "training" exercise where they got to experience the feedback of the motors at the three distances in every direction.

11. The experiment (steps 6-9) was then repeated, using different predetermined directions and distances from the initial test.

12. The participant's guesses were recorded and graphed.

Figure 5 - Test area

Figure 6 - Participant in test

Software Development and Algorithm

The final program as well as test programs were developed in the Arduino Windows Application using the Arduino Language (subset of C/C++)

START.

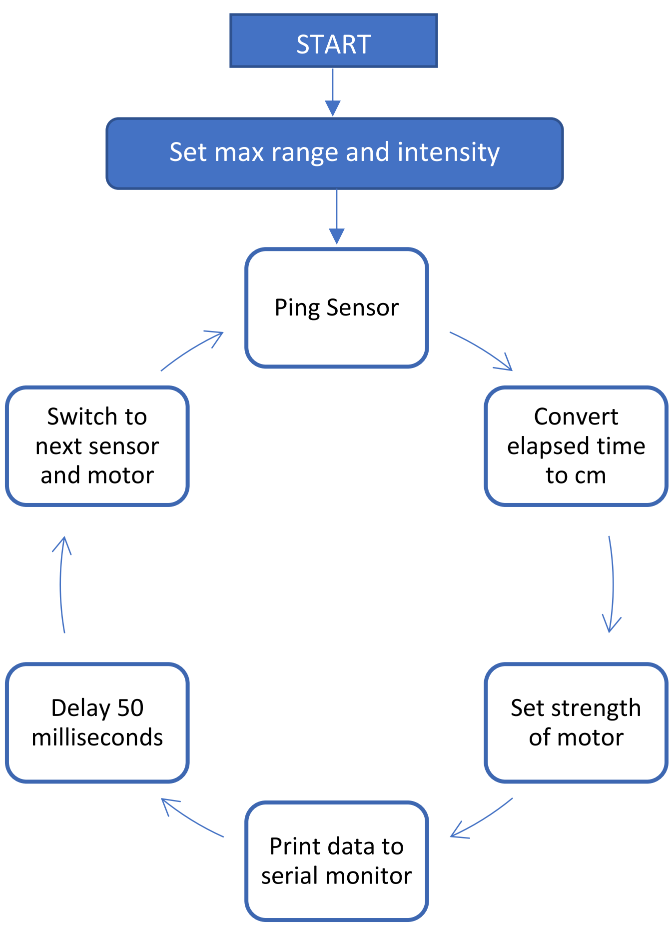
1. Declare all variables. Create integer array for sensor pins and motor pins.

2. Set the range (1cm – 500cm) and the intensity of the vibrations (0.0 – 1.0).

3. Set the data rate to 9600 bits per second for serial data transmission.

LOOP. (Constantly polling in clockwise order)

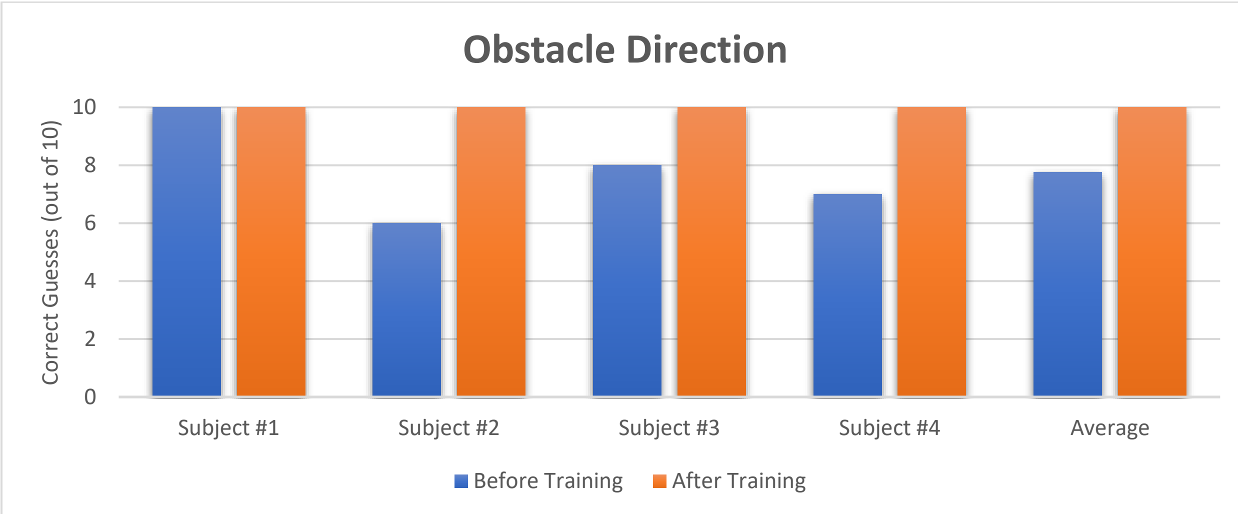
1. Ping ultrasonic sensor. Get elapsed time in microseconds. If the sensor picks up no reading (e.g. object is further than 500cm away), then return 0 and continue.
2. Convert elapsed time from microseconds to centimetres. Multiply the duration by the speed of sound, and divide by 2 since the sound wave travelled to the object and back (duration x 0.034 / 2).
3. Set power of vibration motor if distance is in range. The power is linear, with a minimum of 40 at 0cm, and a maximum of 150 at the top of the range.
4. If distance is out of range, turn vibration off.
5. Print data to serial monitor. (For testing purposes)
6. Delay code for 50 milliseconds to allow for sound waves to dissipate.

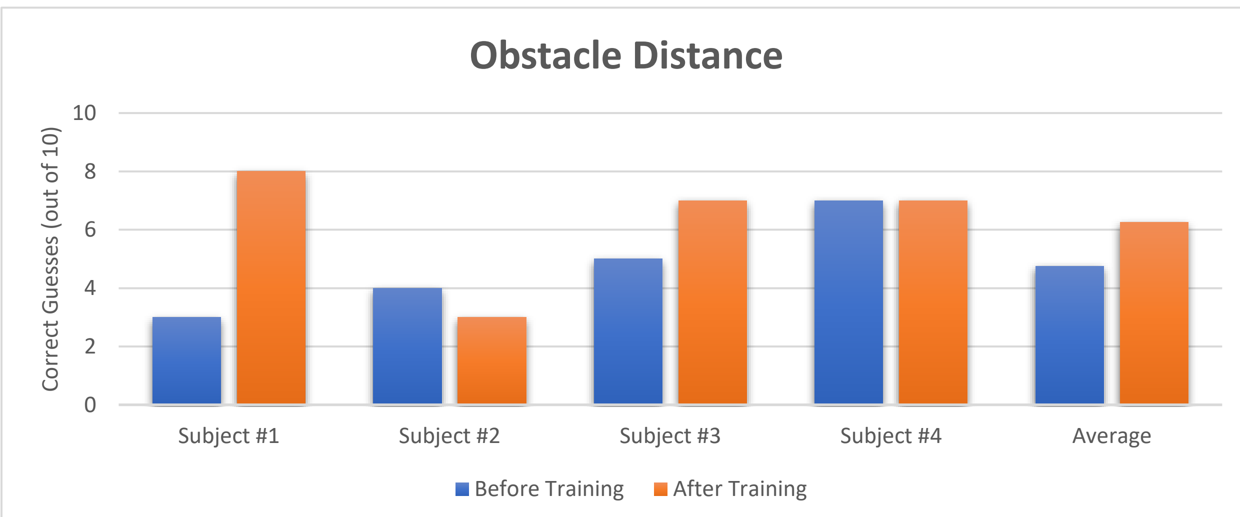


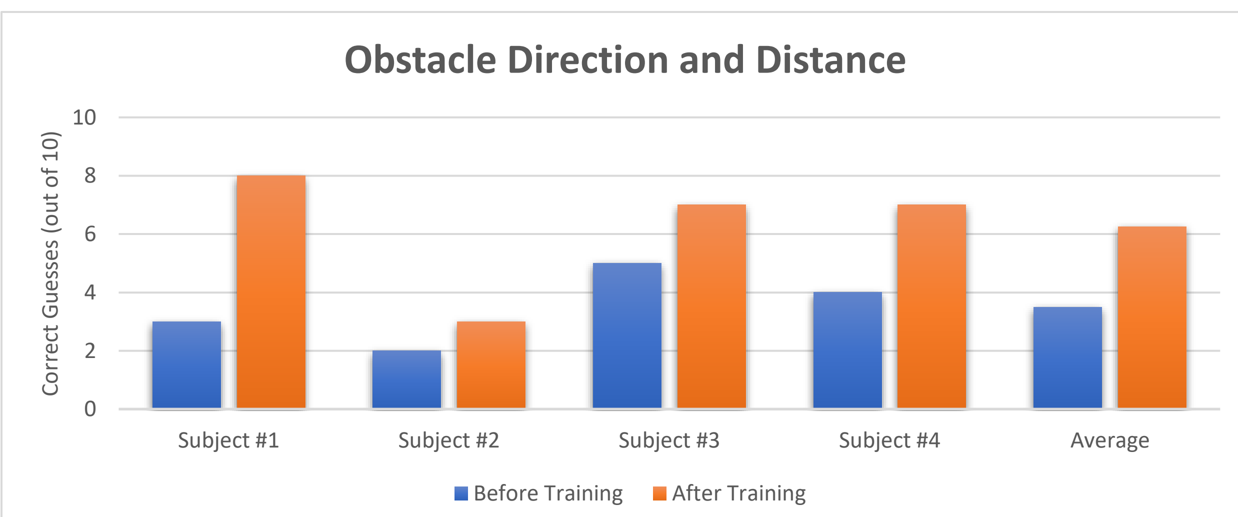
```
//include NewPing Library
#include "NewPing.h"
//define constants
#define TRIG_PIN_1 2
#define ECHO_PIN_1 2
#define TRIG_PIN_2 4
#define ECHO_PIN_2 4
#define TRIG_PIN_3 7
#define ECHO_PIN_3 7
#define TRIG_PIN_4 8
#define ECHO_PIN_4 8
#define TRIG_PIN_5 12
#define ECHO_PIN_5 12
#define TRIG_PIN_6 13
#define ECHO_PIN_6 13
#define SONAR_NUM 6
#define MAX_DISTANCE 500
#define MOTOR_PIN_1 3
#define MOTOR_PIN_2 5
#define MOTOR_PIN_3 6
#define MOTOR_PIN_4 9
#define MOTOR_PIN_5 10
#define MOTOR_PIN_6 11

NewPing sonar[SONAR_NUM] = {
  NewPing(TRIG_PIN_1, ECHO_PIN_1, MAX_DISTANCE),
  NewPing(TRIG_PIN_2, ECHO_PIN_2, MAX_DISTANCE),
  NewPing(TRIG_PIN_3, ECHO_PIN_3, MAX_DISTANCE),
  NewPing(TRIG_PIN_4, ECHO_PIN_4, MAX_DISTANCE),
  NewPing(TRIG_PIN_5, ECHO_PIN_5, MAX_DISTANCE),
  NewPing(TRIG_PIN_6, ECHO_PIN_6, MAX_DISTANCE)
};

int motor[6] = {MOTOR_PIN_1, MOTOR_PIN_2, MOTOR_PIN_3, MOTOR_PIN_4, MOTOR_PIN_5, MOTOR_PIN_6};
long duration;
int cm;
double range = 160.0;
double intensity = 1.0;
int strength;

/*// Array of Ultrasonic sensor pins
int sensors[] = {3, 2};

//create array for 8 ultrasonic sensors*/

void setup() {
  // put your setup code here, to run once:
```

```
void setup() {
  // put your setup code here, to run once:
Serial.begin(9600);
}

void loop() {
  // put your main code here, to run repeatedly:
  int prev =0;
  int prevprev = 0;
  for(int i = 0; i < SONAR_NUM; i++){
    duration = sonar[i].ping();
    cm = microsecondsToCentimeters(duration);
    Serial.print(i);
    Serial.print(": ");
    Serial.print(cm);
    Serial.print("cm   ");

    //change motor speed
    if (cm > 0 && cm < range)
    {
        strength = 40 + 110*((range-cm)/range*intensity);
        analogWrite(motor[i], strength);
        Serial.print(strength);
        Serial.print("str    ");
    }
    else
    {
        analogWrite(motor[i], 0);
    }

    //allow for sound to dissipate
    delay(50);
  /*for (int i = 0; i<2; i++){
    //Ping(sensors[i], i);*/

  }

  Serial.println("");
}

int microsecondsToCentimeters(long duration){
  // Distance = Time * Velocity
  // The speed of sound is 340 m/s
  // Divide by 2 because the sounds must travel there and back
  return duration*0.034/2;
}
```

Observations







Analysis & Conclusions

The results support the original hypothesis, where by using ultrasonic sensors and vibrations motors which vary their intensity according to the distance of an obstacles, users' ability to determine the direction and distance of an obstacle while using the Echo Belt improved after a brief training exercise. The device was very successful in allowing users to determine the direction of an obstacle, where after the training exercise, users correctly guessed the direction 100% of the time. Although users couldn't predict the obstacle's distance with as high of an accuracy (62.5% of the time), most incorrect guesses were within 0.5m of the correct distance. Also, users shared feedback that some motors were stronger than others, which is likely due to the quality of the parts. The device was easy for users to pick up, since with about only 10 minutes of use, users' ability to determine an obstacles direction and distance almost doubled. With continued use of the device, users will have more experience with determining the different intensities of the motors, and their ability to judge an objects distance would likely improve as well.

Further testing was done at the W. Ross Macdonald School for the Blind. Students and staff with varying degrees of visual impairment (some completely blind, others low vision) tested the belt and gave feedback. Similar to the first test group, participants were able to successfully detect obstacles around them with high accuracy. One student pointed out how this device could be used with a white cane, since the cane is not meant to be raised and can therefore not detect waist-high obstacles. It was also observed that some participants were less sensitive to vibrations than others, so it is important that the strength of the motors can be changed. There was some interference affecting the ultrasonic sensors, and upon further research, it was likely due to air currents from pneumatic equipment or fans (e.g. air conditioner) disturbing the path of the ultrasonic wave.

Applications

The "Echo Belt" would benefit anyone suffering from visual impairment, especially those with less severe vision loss, since it is discrete and non-intrusive for others. Furthermore, the total cost of the device is under $40, making it affordable for many people. The "Echo Belt" requires very little no to training to operate, while other alternatives require weeks of training to use. It functions well to detect obstacles not only in front of the user, but all around, similar to how people with normal vision can see out of their peripheral or turn their head at a moment's notice. Users could avoid obstacles which are approaching from behind, something which would be otherwise impossible to do. By having both hands free, the user has a more "natural" travel experience, where they could better greet people, order food, carry objects, and do other daily tasks. By making "travel" a less stressful task for the visually impaired, their quality of life will be improved and can be better integrated into society from the functionality and ease of use of the device.

Future Directions

Future development of the "Echo Belt" would include new hardware and features to make the device even more functional. This includes the addition of more ultrasonic sensors and vibration motors to achieve a full 360° field of view. This would require a larger microcontroller, such as the Arduino MEGA micro-controller, to house all the pins. Also, having higher quality vibration motors will improve precision of the haptic feedback. To allow for functionality on the sides, wristbands with an additional sensor and motor would be required since the arms would interfere with the device. Having one buckle on the side means the device had to be realigned every time someone with a different waist size used the belt. Instead, two clips would be installed on the sides, allowing the belt to be readjusted at two points and therefore no aligning would be required. To detect tripping hazards which are lower than thigh height, such as curbs or bumps, this system could be implemented in the toes of people's shoes. By attaching a GPS module to the device, the belt could connect with the user's smartphone to give directions in the form of vibrations.

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