Smart Cane

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Abstract

The white cane, due to its primitive design, is unable to offer the blind and visually impaired a level of independence that is achievable with modern technology. The Smart Cane looks to upgrade the white cane by increasing security and usability of the cane while ensuring an affordable price for an older and lower income demographic. This was done by including an ultrasonic sensor to detect potential obstacles at an extended distance from the user, vibrating motors to alert the user of these obstacles via haptic feedback, and an adjustable and ergonomic handle in order to increase the comfort and ease of the cane. Observations and basic testing confirm the effectiveness of the vibrations in the handle and the accuracy of the ultrasonic sensor up to 1.5 meters past the tip of the cane.

1. Introduction

Consumer and medical technology has made significant advancements over the past 60 years. However, the functionality of canes for the visually impaired remains limited, relying on the user's ability to physically detect objects and forcing the user to be entirely responsible for their safety. This burden can be mitigated with the added security of an object detector. In addition, the standard white cane has no range of physical options. It places additional burden on the user by forcing a change in handle grip depending on how crowded the surroundings are. The white cane thus requires the user to adapt to the cane rather than having a cane that will adapt to the user.

To address these shortcomings, The Smart Cane project examines how canes can be technologically equipped to improve their functionality in a way that is also economically accessible. The goal for the Smart Cane project is to eliminate this problem by designing, building, and testing a cane for the blind that utilizes computer and sensory technology to provide object detection capabilities and freedom of physical range. Once the project is completed, the cane design will be quantitatively and qualitatively examined to determine its success as a product.

2. Background

2.1 A Brief History of the White Cane

The white cane originated in Europe in 1921 when James Biggs, a photographer who had lost his vision, began to paint his walking cane white to alert others to his presence.[1] When veterans of World War II returned to America with vision impairment and blindness they wanted to have the same level of independence as they had before the war. Because of this, the white walking cane was altered into the long cane form that is still prevalent today.[2] At present, 82% of the world's blind population are at the age of 50 and above. Approximately 90% of the world's visually impaired live in developing nations due to the lack of healthcare and medical treatments.[3] These figures are important when considering the population that the Smart Cane will be addressing.

2.2 Characteristics of the Blind and Visually Impaired

A person who has been clinically determined to have a visual acuity of 20/70 or less in the stronger eye is diagnosed as visually impaired, while a person who is legally blind is defined to have a visual acuity of 20/200 or less in the stronger eye. People whose visual acuity is at either of these levels receive governmental benefits, such as the right to possess a white cane or own a guide dog.[4]

A white cane is often carried by the blind and visually impaired to give more freedom to the individual. The two main functions of the cane are identification and safety; it should alert the user to obstructions and changes in their path and also notify the seeing pedestrians and drivers that the user has some degree of vision loss.[5] There are three types of white canes: identification canes, support canes, and long canes. Identification canes are short (reaching only to the user's waist), provide little to no protection, and are generally more popular with the visually impaired who only want to alert others of their impairment. Support canes have the same purpose as identification canes, except that they provide more support and balance for the legs and body of the user. Long canes, the type of cane chosen to be modified into a Smart Cane, reach the user's sternum and provide the most safety for the user, alerting them of terrain and height changes, walls, doors, and obstacles. They are also the most visible to others.[6]

2.3 Traditional Cane Technique

Training for white cane use usually focuses on two major topics: grip and arc. For outdoor use, where a person's pace is faster and more regular, the proper grip used to hold the white cane is the palm facing up at waist height with the index finger pointing along the cane and the remaining fingers and thumb wrapping around the cane lightly. When indoors or in a more congested environment, such as a crowded city street, the grip changes in such a way that the user holds the cane as if it were a pencil: upright, at sternum height, and closer to the body. With both grips, the elbows are kept tucked close to the body.[7]

The second component, the arc, refers to the sweeping motion of the cane performed by the user. The user sweeps the cane over an area just larger than shoulder width, tapping the ground on the opposite side of the foot currently taking a step in order to prepare for the next step (for example, tapping the ground to the left of the body when stepping forward with the right foot).[8]

2.4 The Arduino

The Smart Cane's sensors and motors are powered by an Arduino microcontroller. The Arduino is a programmable electronic platform which allows users to easily create prototypes. Along with a breadboard and other pieces of circuitry equipment, the Arduino can be used to make various electronic input, output, and sensory systems. Aside from basic electronic hardware, a wide range of complex devices, including sensors, are made to be compatible with the Arduino system. The Arduino programming language is C based, and can be used to create a wide variety of programs. The Arduino is also made more accessible by its low cost. Most boards (including the Uno, which the Smart Cane uses) cost less than $30.[10]

2.4.1 Pulse Width Modulation

The Arduino allows for input and output by plugging wires into 'pins.' Input pins read data (such as information from a sensor), and are capable of taking in a continuous range of values. Thus, through sensors, the Arduino can be continuously updated with information about the environment around it. The output pins send a current to any device connected to them, such as a motor or a light bulb. Unlike the input pins, there are only two possibilities for the voltage: 5V or 0V. Gradually changing the speed of the motor requires a continuous change in voltage, which is not possible with the output pins.

However, the Arduino does allow for (and has special output pins dedicated to) pulse width modulation (abbreviated as PWM). Instead of ranging over many voltages, the voltage rapidly changes from 0V to 5V. Essentially, PWM simulates a gradual change from one voltage to another, allowing for anything connected to the pin to also vary along a continuum. For example, if 5V are being outputted one fifth of the time, this is known as a 20% duty cycle, and the simulated voltage is one fifth of 5V, i.e. 1V.

A function built into the Arduino, analogWrite(), allows a program to make use of the PWM function simply by plugging in a value ranging from 0 to 255, with the latter being the maximum possible voltage (a continuous output of 5V).

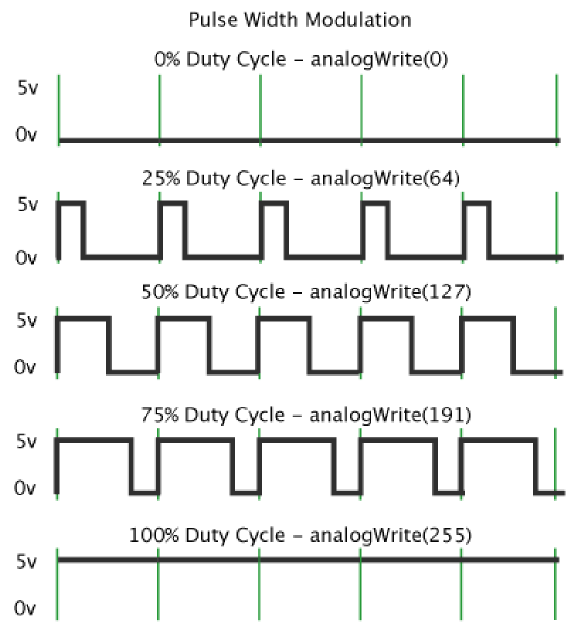


Figure A. This diagram shows how the number of pulses sent changes depending on the analogWrite value.

2.5 The Ultrasonic Sensor

The sensor used in the Smart Cane is the RadioShack® Ultrasonic Range Finder. It functions by sending out an extremely high frequency sound wave from one speaker, which is deflected by obstacles directly in its path. Using the speed of sound through air at room temperature, the distance of the obstacle from the sensor can be calculated from the time it takes the ultrasonic pulse to leave the sensor, reflect off the nearest object, and return to a second speaker.[11]

Figure A. This chart shows how changes in the analogWrite value affect the number of pulses sent by the Arduino.

$$346.5\frac{m}{s} = \frac{d}{\Delta t}$$

The specific distance is calculated by the sensor and is outputted to the Arduino. This data is made accessible to the Arduino through code released by RadioShack® under a GNU General Public License.

The detecting range of the sensor is from 3–400 centimeters, with a detecting angle of 30 degrees.[12] However, the accuracy of ultrasonic sensors is limited not only by distance, but also by the surfaces of detected objects. A surface that absorbs sound or causes echoing, such as foam, would result in inaccurate readings.[13, 14]

2.6 The Ardumoto and its Applicability

The Ardumoto is a shield, or a circuit expansion board, for the Arduino. It is designed to run two motors, making it a convenient addition to the electronic setup of the project. The Ardumoto is able to control motors in many ways through an analog input for the motor speeds, on and off features, direction features (whether the motors spin clockwise or counterclockwise), and much more. The electronics setup for any motor experiment on an Arduino Uno alone is very complicated, and often requires a tedious search for the right resistors, transistors and diodes to properly control the motor. The Ardumoto simplifies this process significantly when it comes to coding as well as electronic setup.[15]

2.7 Materials Used in the Traditional Cane

The white cane was originally constructed out of wood, but aluminum

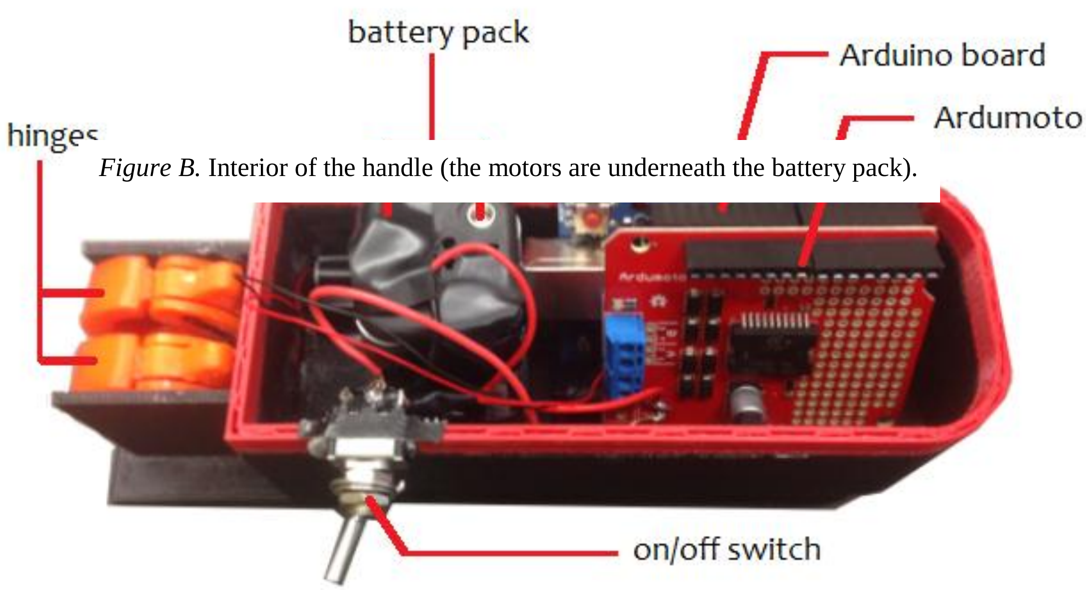


Figure B. Interior of the handle (the motors are underneath the battery pack).

quickly replaced the perishable material. However, it was found that aluminum canes bend and break very easily if they get caught in cracks or crevices. In present day, the most popular materials are fiberglass and carbon fiber, both of which have their own individual pros and cons.[16] Fiberglass canes are reasonably priced and can bend slightly, but will ultimately return to their original shape. White canes made of fiberglass tend to be heavier, although new innovations in materials have created types of lighter fiberglass. Carbon fiber canes are more expensive than aluminum and fiberglass canes, but also significantly lighter. While carbon fiber canes do not bend as much as the canes listed above, they are the easiest to break.[17]

3. Materials and Methods

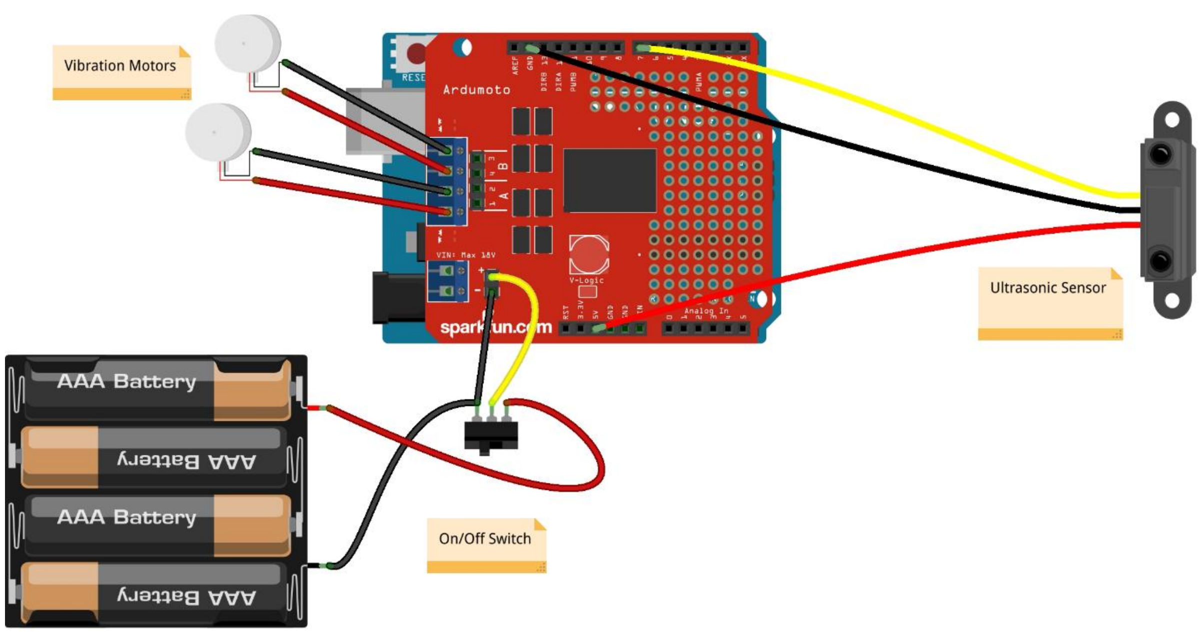
There were two main components that were the focus of the Smart Cane design process: updating the basic mechanics of the traditional white cane and integrating technology in order to make it "smart". It was concluded that both would be addressed, first by making the handle adjustable and then by adding a sensor that would extend the range the user could observe. The detection of potential obstacles would then be transmitted to the user through vibrations in the handle.

3.1 Implementing the Feedback System

The device that alerts the cane's user to objects in their path is the vibration motor. The motor is housed in the handle of the cane, and is connected to the Arduino. The Arduino analyzes data from the ultrasonic sensor, and it is this data that is sent to the vibration motor in the form of a corresponding PWM duty cycle. Depending on the number of pulses, the vibration motor receives varying amounts of power, which causes the vibration motor to spin at differing speeds. These speeds vary discretely instead of continuously, so that a given range of distances will correspond to one vibration intensity. Additionally, each distance will also correspond to a certain delay between vibrations, with greater distances having greater delays. These vibrations, caused by a weight spinning on the motor, will oscillate through the handle to alert the user.

3.2 Creating the Ergonomic Handle

Besides the sensory system itself, the most innovative and important aspect of the



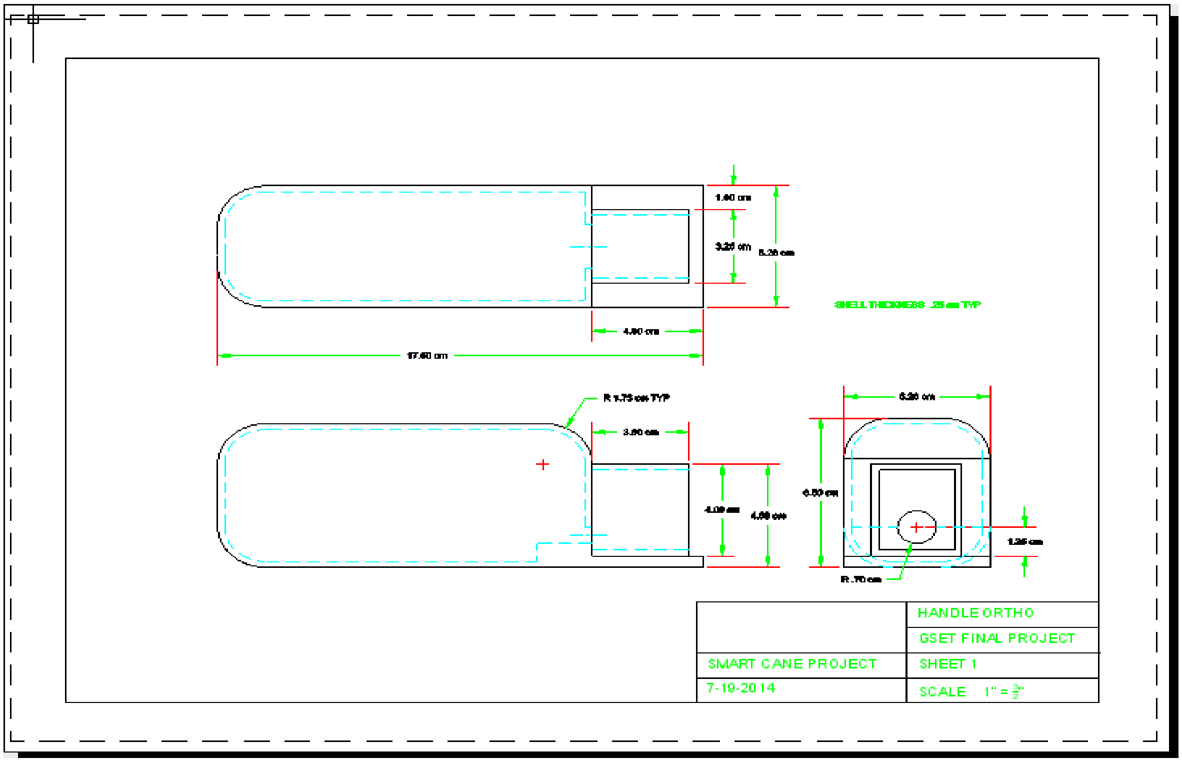


Figure D. Orthographic depiction of cane handle drawn using Autodesk AutoCAD

Smart Cane is the hinged ergonomic handle. The design began with preliminary measurements and sketches. Then, the cane handle was designed and modeled in 3-D using Autodesk AutoCAD software. After being converted to an STL file (the file used by most 3D printers), the cane handle was 3-D printed in two parts, the top half and bottom half. This allowed for the Arduino and vibration motor to be placed inside of the cane handle. The handle is made of ABS plastic and is attached to a hinge created with two plastic cable cuffs. Inside the handle are two vibration motors connected to an Arduino board. A hole at the hinged end of the handle allows the wiring from the Arduino and vibration motor to connect to the battery pack, power switch, and ultrasonic sensor no matter what position the cane is in. These wires are threaded through the hollow PVC tubing of the cane. Completing the comfortable design of the handle is a rubber grip that covers the handle and prevents the user's hand from slipping. Overall, the handle was designed with the cane's target demographic in mind; the handle's top design priority was comfort for the average elderly user.

4. Results and Discussion

4.1 Case-Specific Examples

The following cases are two examples of white canes that have been merged with technology to better the living quality of the blind and visually impaired. These examples highlight the similarities and differences between the Smart Cane and other advanced canes on the market.

4.1.1 UltraCane

The UltraCane, a cane developed and produced by Sound Foresight Technology Ltd., is a technologically enhanced white cane that uses ultrasonic waves to detect potential obstacles in the user's path.[18] Similar to the Smart Cane, it has two vibrating motors located in the handle. The vibrating motors provide a haptic form of feedback, alerting the user of the obstacle's location (in front of or above the user) and distance from the user. Two ultrasonic sensors, both placed on the handle, emit waves in three different ways: in front of the user across a long range distance of 4 meters, in front of the user across a short range distance of 2 meters, and directed at an upward angle that can detect across 1.6 meters.[19] The UltraCane's current price is £635.00 ($1086.45).[20]

4.1.2 BlindSpot

The BlindSpot is a concept cane created by Selene Chew, a National University of Singapore graduate student.[21] The BlindSpot hooks up to the user's smartphone and connects to the phone's GPS, internet, and social network data. The user could get directions through the GPS or access the internet via voice commands through the Bluetooth earpiece that would come with the cane.[22] Utilizing the access to the user's social networks, the cane would identify and alert the user if a friend is in a nearby location and prompt them through the earpiece if they would like directions towards their friend. The cane would have ultrasonic sensors built into the shaft that would scan the arc on their own, substantially reducing the need for the user to sweep the cane. The BlindSpot, with its roots in social networking, is designed to be a more social cane than one geared towards independence and functionality.[23]

4.2 Range and Accuracy of Ultrasonic Sensors

To measure the success of the Smart Cane design, various tests were conducted to see how the cane would detect objects. In particular, these tests check the detection capabilities of the ultrasound given the design and position of the cane. These tests are necessary because they can provide an

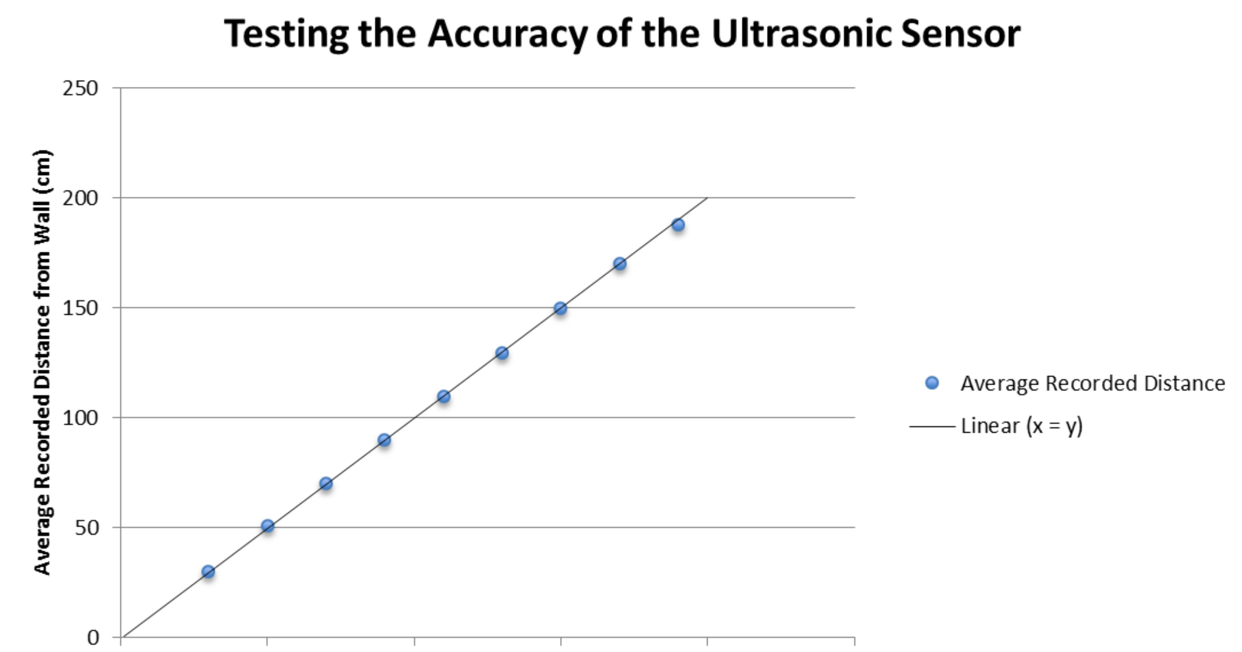


Figure E. This graph charts the actual and observed measurements against the graph that would result if there was no error.

indication of the situations in which the Smart Cane would perform inadequately.

The first test investigated how well the cane detected stationary objects at varying distances. The cane was placed in the same way it would be if a visually impaired person were holding it. A direct comparison was made by placing objects at different distances from the cane and comparing the observed distances with the distance readings outputted by the sensor. The sensor was tested at distances ranging from 30 to 200 centimeters, with an average percent error of 0.20% and a maximum error of 1 centimeter.

The second experiment investigated how well the stationary cane observed a moving object. In the experiment, a small robotic car moved past the ultrasound sensor at 0.8 meters per second. The car was set at various distances away from the ultrasonic sensor in increments of 20 centimeters. It was determined that with this grip and object speed, the ultrasound sensor slowly grew less and less accurate as the distance from the object increased. In addition, the ultrasound distance reading immediately after the measured reading was always completely inaccurate.

Although there are some minor discrepancies when the cane is in motion, the discrete mapping of vibration intensities unto distance values means this error will have little or no effect on the vibration felt by the user.

The ultrasonic sensor also presented problems with detecting objects reliably while the cane was swept over a unit of area. Since the cane was moving in a circular motion, the sensor could not focus on one object. The ultrasound would occasionally pick up certain objects and send PWM signals to the motor, causing random vibrations that would serve no purpose to the user–the user needs consistent vibration to react to a nearby object. This problem was addressed by reducing the range of detection of the sensor. The ultrasound still detects objects in a 6-7 meter radius, but it only passes PWM values to the motor for objects within a 2 meter radius. By reducing the radius of detection, the ultrasound was able to do a better job of consistently detecting objects.

4.3 Issues with Motors

When programming the Arduino, it was difficult to make the vibration intensity change in such a way that the user would notice a significant decrease (or increase) in distance. As with the previously mentioned accuracy problem, this issue was addressed when the vibration intensity was made to change in increments. Because bigger changes are more noticeable than gradual ones, the user would become aware of a significant decrease in distance almost immediately. Additionally, the delays between vibrations would also increase incrementally, so that a smaller distance corresponds to a lower vibration intensity and to a smaller delay between vibrations.

Finally, PWM itself was extremely difficult to achieve. On the Arduino Uno board, despite an accurate setup involving a resistor, transistor, diode, and various pins from the Arduino, it was impossible to achieve the necessary PWM. After much experimentation, using the Ardumoto made the process of controlling PWM a success.

There were also more construction oriented problems with the motor. The vibration motors used in the prototype are small relative to the entire handle. If the motors are not fixed in place, the vigorous vibration causes the motors to move around in the handle and make loud rattling noises as they collide with the hard surface of the inner walls. This is undesirable because the noise is distracting and it can confuse the user–as stated earlier, the rate of discrete vibrations is an indication of proximity to the detected object, and collision may detract from the user's ability to understand the vibrations. The best solution to this problem would be to simply fix the motors in place with tape.

5. Looking Towards the Future

5.1 Changes in Materials Used

The prototype has been constructed under time constraints with a limited range of materials. In the future, mass production of this product can make way for numerous circuitry changes. The Ardumoto (or any microcontroller shield for that matter) would not be necessary. The only reason it was used was because controlling PWM was very difficult on the Arduino alone. In the future, the Ardumoto would be replaced with significantly cheaper components, such as transistors, diodes, and resistors.

Additionally, a model could be produced which uses a single-purpose microchip instead of an Arduino. Such a simple microchip would be extremely cheap to produce, ensuring that the Smart Cane would be affordable to the demographic groups most likely to suffer from visual impairment. Only a small percentage of the Smart Cane's users would be able to take advantage of the Arduino's versatility, this change would have no impact on the quality of the product.

The commercially produced Smart Cane which would use the Arduino would most likely contain the Arduino Micro, although other models could be used instead. The Micro, in comparison to the Uno, has equivalent or superior specifications (CPU speed, RAM, Flash, etc.) and the same number of pins (input and PWM), but has different microprocessors. The two major differences that make the Micro more appealing than the Uno are the lower cost and smaller size. The lower cost would make the Smart Cane even more affordable, while the smaller size would allow the Arduino to better fit inside the cane handle. The programmability of the Arduino in the Smart Cane would give the user more control over their cane and allow additional hardware (such as GPS or Life Alert ® technology) to be added to the device.

The shaft would be constructed out of an affordable variety of fiberglass, which is lighter than PVC pipe or plastic and therefore is more comfortable for the user to hold when sweeping the cane. The hinge used to connect the handle to the shaft would be a locking angle hinge, and the handle itself would be wrapped with a more comfortable and ergonomic material.

One of the main advantages of the Smart Cane over similar "enhanced" white canes is its relatively low cost. This makes it accessible to the demographic groups that are most likely to be visually impaired. The following table lists expected costs of the supplies necessary to build the future cane.

Item	Cost*
Insulated wiring (5 feet)	$2
Misc. Circuit Materials (transistors, resistors, diodes switch,)	<$6
Vibrating motor	$2
Ultrasonic sensor	$5
Arduino Micro	$20
Hollow fiberglass cane	$20
Handle	$10
Batteries and battery pack	$5
Total	$70

It is important to note that these prices are based on current consumer prices, which may be more expensive than what a manufacturing company would pay when buying in bulk. Additionally, costs for certain products, such as the Arduino board, would most likely decrease with time.[24] However, the above listed costs are only supply costs for one cane and do not account for the resources necessary to manufacture the final product.

5.2 Additions to Design

The Smart Cane of the future would have many new features in addition to those that are currently implemented. It would have a rechargeable, long-lasting battery pack that would allow the user to use the cane without having to worry about bringing extra batteries. Another addition that the Smart Cane would likely see is a GPS monitoring system. This optional system would allow a family member to connect to the Smart Cane, and be able to track the whereabouts of their visually impaired family member. This could be very useful in a situation where the Smart Cane user becomes lost, or has a medical emergency.

The GPS system ties in with another innovation: a Life Alert ® connection that would be built into the cane. This would allow the user to call for emergency help by simply pressing a call button on the handle of the cane. Unlike cell phones, the visually impaired user would not have to manually dial 911 and it would be impossible for them to forget the device since it would be built into the cane.

One more possible addition to the Smart Cane would be a collapsible design that would fold up to allow for easy storage. This would decrease the Smart Cane’s size while still offering the greater range that comes with the ultrasonic sensor. Although these additions would increase the price of the Smart Cane, the design would still attempt to remain faithful to its original customer demographic by keeping the cost as reasonable as possible. Overall, the goal of these future plans is to further improve the lives of the blind and visually impaired by giving them increased security and greater independence.

5.3 Future Testing

To further enhance and improve the reliability and functionality of the future Smart Cane, tests and surveys would be

* The following costs are estimates based on common retail prices listed by vendors such as Amazon.

conducted among a subject group consisting of blind and visually impaired participants over multiple demographic groups. These tests and surveys would collect data on the subjects' opinions on many different aspects of the cane, including indoor and outdoor use, convenience, and comfort, while also collecting any additional feedback on the cane the subjects have to offer. Ideally, each subject would receive a Smart Cane to replace their original white cane for the duration of the testing, which would last anywhere from a few days to a few months.

Another crucial test would measure user sensitivity to changes in the vibrations of the motor. As of now, it seems reasonable that the combination of varying intensities and interrupted vibrations provides a strong indication of proximity.

In addition to vibration, the prototype needs to be adjusted to perform differently depending on the environment. It needs to be able to account for situations such as crowded areas, open areas, rain, and snow. Additional testing would be needed to determine the optimal cane position, hinge angle, and ultrasound settings in different situations.

One of the major considerations with the ultrasound detector is making sure that it can detect objects properly while it is swept. It was found that reducing the range of detection (where the Arduino does not process distances greater than a certain threshold value) allows for more accurate detection. This tradeoff between range of detection and accuracy of detection needs to be further explored in the future to find an optimal balance.

Another consideration is how the accuracy of the distance reading is affected when a moving ultrasound source tries to detect a stationary object. The primary difficulty with creating a controlled experiment is maintaining a constant sweep rate with the cane. As stated earlier, the cane sweeping motion is in an arc, and ensuring a constant speed over an arc seems difficult to achieve without machinery.

6. Conclusion

The Smart Cane's goal is to bring the white cane up to technological modernity while maintaining its affordable price. The Smart Cane is geared towards an elderly, less affluent demographic group that would demand comfort, accessibility, and affordability from the product. Observations and test results prove that the Smart Cane reached its goal and satisfied the needs of its target demographic. Using the ultrasonic sensor, Arduino board, and vibration motor, the Smart Cane greatly increased the object detection range of the white cane, thereby improving the lives of the blind and visually impaired users. Besides the cane's technological improvements, the design was altered to give the user a more comfortable and ergonomic handle. Along with the locking hinge system, the Smart Cane's handle alleviates the need for the user to change their grip on the handle based on their cane's position. Overall, the Smart Cane's use of technology and ergonomic design has greatly improved upon the traditional white cane, and has taken a great leap towards improving the lives of the visually impaired.

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