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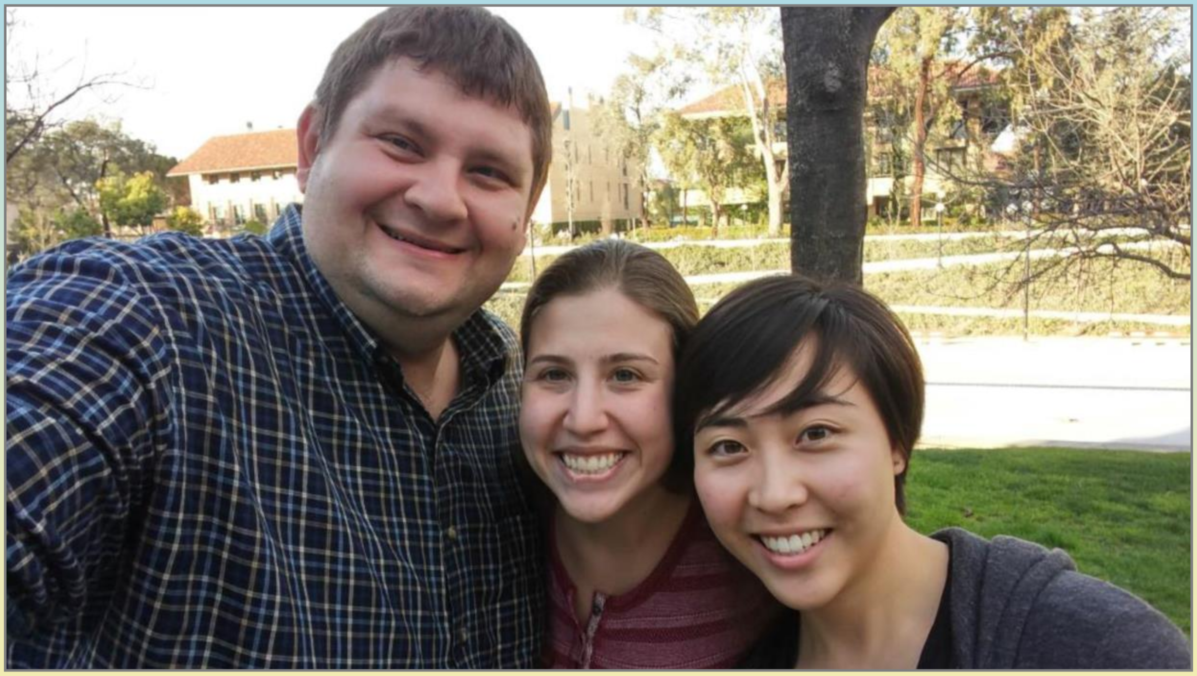
Jogging and Running Aid for the Blind and Visually Impaired

Final Report



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Abstract

While many devices exist for the assistance of the visually-impaired, very few of these devices are specifically designed for a user with an active lifestyle. For example, white canes are meant to be tapped alternatingly with each step [1], while rollators require both hands to travel safely in a straight line [2]. Just these two examples already illustrate a problem that most mobility devices share: when travelling at a pace faster than a slow walk, the devices become cumbersome and even unstable for safe use.

Thus, our team's focus was to develop a device that would allow the user to move safely and confidently at a jogger's pace while not interfering with the body's natural jogging movements.

In developing this device, current assistive technologies were examined for strengths and weaknesses, and new designs were drawn up. Subsequently, a series of iterative prototypes were built to allow us to discover key benefits and flaws that were previously unknown during the brainstorming process.

To that end, our current prototype allows for a natural, comfortable gait when jogging while providing haptic feedback from both direct surface contact and indirect ultrasonic sensing. Intentional focus on the ergonomics of assisted jogging and feedback from the environment – led to the development of a device that can be confidently used in its current form, or further utilized as a platform for testing new sensing technologies or techniques.

Contents

Introduction

According to the World Health Organization, there are over 285 million visually-impaired people around the world. Of these, approximately 39 million people are considered legally blind [3].Yet, despite this impairment, most of them continue to lead lives filled with exercise and activity. While they may choose different avenues of exercise, many enjoy jogging [4].

However, for the visually-impaired, jogging provides numerous challenges that are not present when walking at a slower pace. For example, research has shown that visual impairment affects the dynamic stability of gait, meaning that stride length and cadence are negatively affected when the jogger cannot see [5]. Furthermore, imperfections in the jogging path, such as cracks in a sidewalk or tree roots on a trail, can cause a greater likelihood of tripping due to lack of environmental awareness. And because joggers typically move at a faster pace than walkers, they have less time to react to obstructions (moving or stationary) in the path. However, even with these inherent difficulties, jogging remains a popular pastime.

Compensating for these difficulties requires a jogger to split their attention (and thus their focus) between two areas while jogging: forward towards the direction of travel and downward along the jogging path. Unfortunately, this method makes jogging more complicated, if not impossible, for people who are visually-impaired. The current popular solution to this problem is to run with a jogging guide, a sighted jogger who runs in tandem with the visually-impaired jogger, tethered by the wrists (Figure 1).

However, this solution is still not without its difficulties: it requires schedule coordination, it removes a sense of independence from the jogger by making them reliant on another person, and it instantly identifies the jogger as someone who needs assistance (whether that be the case or not).

Figure 1.
Visually-impaired jogger with tethered jogging guide [15].

Objectives

While many devices exist to assist the visually impaired mobility-wise, almost all tend to fall short in being fully accepted by the user due to three core constraints:

1. Single-tasked: most devices are either canes or rollators, providing either ground-based detection or movement confidence, but never both (as seen in Figure 2 below).

Figure 2.
Current devices available to the visually-impaired typically fall into one of two categories: canes and rollators [6].

2. Uncomfortable: most devices are tiring for use in the long term. In addition, when jogging, if a device becomes a hindrance to the pace of the jogger due to bulk, weight, or other form of discomfort, then the probability of long-term use of the device is greatly diminished.
3. Cost-prohibitive: sturdy folding canes often begin past the $50 price range, while rollators are well above $200. Furthermore, electronic sensors for detecting objects or other hazards are often priced in the several hundred-dollar range, making them cost prohibitive. Unfortunately, about 90% of the world's visually-impaired live in low-income settings [1], thus making these options virtually unattainable.

With these three limitations in mind, we began to focus our efforts on developing a device for visually-impaired joggers that would work both on trails and on the streets, not tire the jogger from use or impair them in any way, and not be prohibitively expensive. In addition, by utilizing microcontroller technology, we wanted the device to be "smart", and allow active feedback of upcoming hazards to the user, freeing their senses and focus. Lastly, a key component in the acceptance of a device is the human aspect, and so we sought to develop a device that would empower the user and make them proud of their device and their own inherent capabilities.

Project Research

Preliminary Research

Preliminary research was conducted by focusing on the most common form of assistance available to people with visual impairments: the traditional white cane. These were examined to understand the mechanics of using a white cane while walking, and to see what other forms of canes were available on the market. In addition, when researching white canes, several useful pieces of information were obtained.

First, the cane is usually held in a pencil- or handshake-style grip, and is then tapped from side to side, one tap per step, and about two inches beyond the width of the shoulders. This rhythmic tapping allows the person to clear an area before stepping into it [1].

Second, different cane tips (Figure 3) provide varying levels of tactile information as well as varying drawbacks. For example, thin plastic pencil tips are light and sensitive to ground details, but have a tendency to get stuck in narrow cracks. Contrarily, rubberized wheels are able to glide over most cracks, but are heavier and add to wrist fatigue [6].

Figure 3.
Pencil and wheel cane tips [1].

Third, many states and countries require white canes to possess a red stripe near the base to allow drivers and pedestrians to be able to identify the visually impaired [7].

Lastly, rectangular assistive mobility (Figure 4) devices are often initially substituted for canes while a person learns how to interpret tactile feedback. This allows the user to adjust to other aspects of cane use, such as mechanics and posture, while eliminating the need to swing the cane from side to side [8].

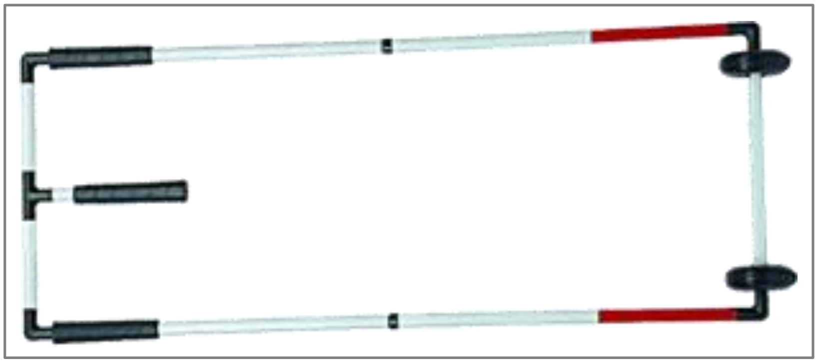


Figure 4
Ambutech assistive mobility device used for training [8].

Research with Project Suggester

Prior to the development or construction of any initial prototypes, the team met with the individual who had initially suggested the project, Brian Higgins (Figure 5).

Brian is a Blind Rehabilitation Specialist with the Palo Alto Veteran's Administration, and is himself visually impaired. In one eye, he is able to perceive the world through a 5-degree field of vision (though hazy), while the other eye is completely blind.

However, Brian's distinction is not that he is visually-impaired, but that he is an avid jogger. He frequently jogs 5-km trails, but needs a device to assist him in detecting obstacles. To that end, he approached Stanford University seeking assistance in developing an aid for visually-impaired joggers.

Figure 5.
Brian Higgins, project suggester and Blind Rehabilitation Specialist [18].

When meeting with Brian, we discussed solutions he had tried in the past that fell short. In particular, the standard white cane, which proves ineffective when jogging due to the bouncing of the cane, as well as the rectangular assistive mobility device, which is flimsy and uncomfortable to use.

In addition, Brian taught us something that was quite revelatory. One of the most important aspects of the white cane is not to detect objects or obstructions, but to provide the user with near-constant contact with the ground. This tactile response is, as Brian stated, "like having a long finger extending from your hand, tracing the ground as you walk". This feedback allows for the user to feel and hear the ground beneath them, understand the quality or changes in the surface, and gain confidence in their movement.

Current Solutions Available on the Market

At present, the only canes marketed for exercise are stability canes with larger bases or bases with 3-4 contact points with the ground. These canes also have more ergonomic grips and pedometers affixed to the cane shafts (Figure 6), but are meant for walking at a leisurely pace.

Figure 6.
Healthmark Alumilite Exercise Cane [19].

As for improvements on the traditional white cane, there is a new category of "smart" cane (such as the SmartCane [9] or UltraCane [10]) that utilizes ultrasonic sensors for advanced notification of upcoming objects. Unfortunately, these "smart" canes can cost over $900, making them beyond the reach of most people, and still have the bouncing problem when jogging, as Brian had mentioned in regards to traditional white canes.

Other solutions exist but rely on technologies that take away the tactile feedback given from true contact with the ground. Devices such as Tactile Navigation's Vibrating Vest [11] and Touch & Go's hand mounted GPS system [12] rely solely on sensor readings or GPS information, both of which can be unreliable and prone to failure. People have even found ways to use products like Google Glass as software-based navigation devices for the blind, though these are inaccurate when not in urban areas [13].

Design Approach

Design Requirements

Following our research, the following design criteria were used as development guidelines:

1. Object detection and feedback: The device should detect upcoming objects near to the ground and indicate their position to the user. In this manner, the user will be able to anticipate any obstacle and adjust their movements accordingly.
2. Terrain detection and feedback: Sudden changes in terrain pose a risk to joggers. Examples include cracks in sidewalks, unstable terrain, and sudden drops or rises. Therefore, it is important to develop a system that will transfer tactile feedback pertaining to the terrain to the user.
3. Stability: When testing Brian's current jogging device (the rectangular training cane shown previously in Figure 4), we observed that the device has a tendency to warp and deform due to its design, and therefore leads the user off a straight path. Therefore, any solutions we develop must be structurally stable and not distracting.
4. Impact on jogging style: We want our solution to enable users to jog freely, and not hamper them with unnecessary constraints. Therefore, potential designs must not conflict with the posture or hand-position of the jogger.
5. Prolonged use: Brian's jogs tend to last about 90 minutes, so we wanted a device that he can use the entire time without creating discomfort or extraneous effort that might prevent continued use.
6. Adaptable to many users: While we are designing for Brian as an initial user, we also want to develop a device that can work in many different situations and for different people with a range of abilities. Therefore, the device must be adaptable and flexible.
7. Safety: The feedback from the device must not require the user's full attention, which would distract from other important environmental feedback such as the sounds of oncoming cars.
8. Trust and adoption of device: While creating a device that accomplishes all of the goals above is important, it is also important to remember that ultimately the user has to trust the device and be confident with it. If the device does not feel safe or is a hindrance, then the user will be less likely to continue using the device. Thus, trust in the device is essential.

Initial Design Ideas

From the myriad of initial sketches and concepts (Appendix A), the most promising ideas were compiled into three cohesive designs. These designs are described below and then compared against each other based on ease of engineering, estimated cost, and user acceptance. All three designs effectively solve the goals of object detection and comfort while enabling a visually-impaired jogger to navigate a path independently.

Idea 1: Cane-less LIDAR Detection

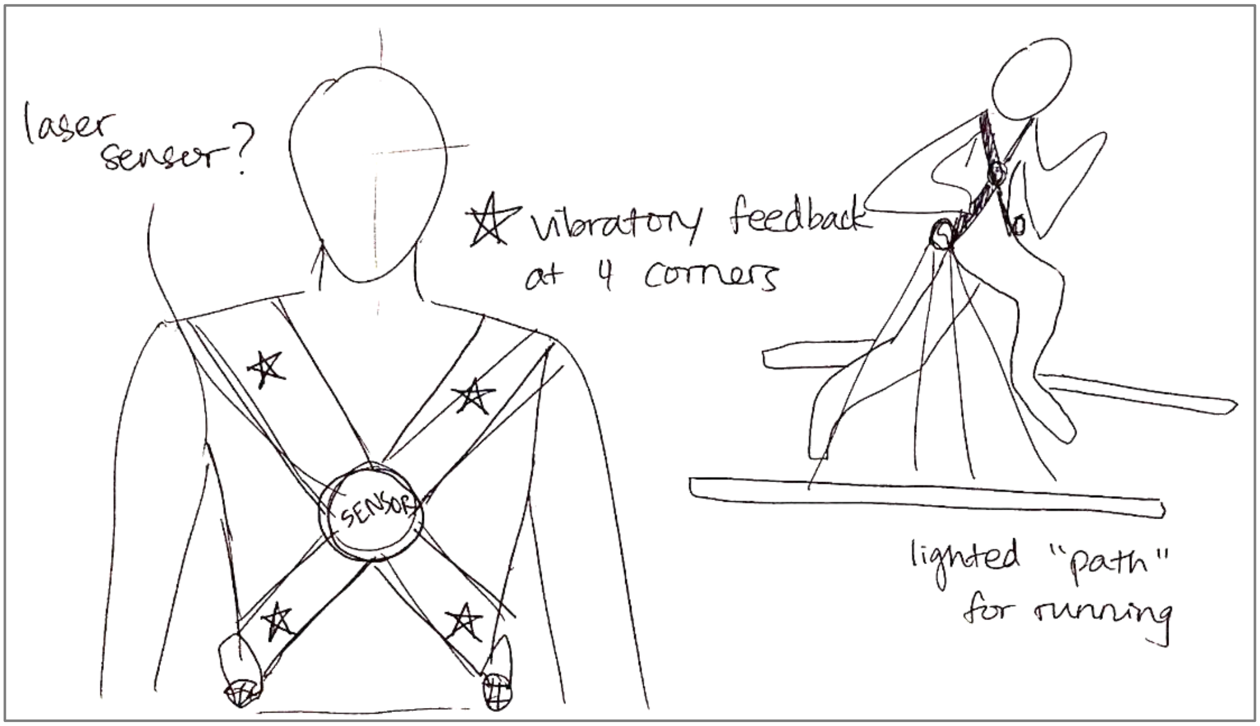


Figure 7.
Cane-Less Wearable Navigation System with Lidar Detection (figure drawn by Alyssa Wei).

This device concept in Figure 7 uses a LIDAR detector mounted at the center of the chest to detect objects anywhere in front of the user. Vibratory feedback on the four corners of the torso allow a user to determine the approximate height and positioning of an upcoming object. Hip mounted lights designate a path on the ground (similar to the bike lights in Figure 8) to alert others of the user's running path.

Figure 8
"Light Lane" device [20].

Idea 2: Simple Skid Cane

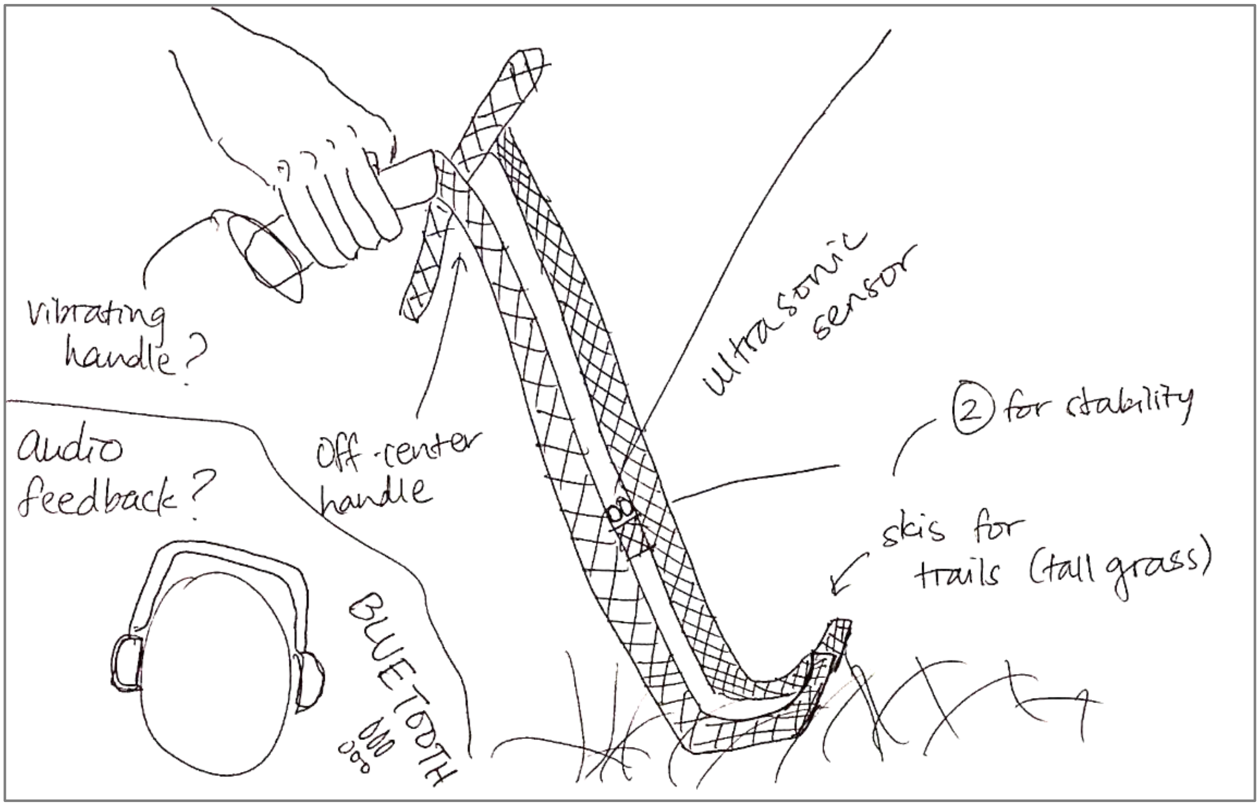


Figure 9.
Paired-Skid Cane with Ultrasonic Sensors (figure drawn by Alyssa Wei).

This simple, rigid device contains a pair of canes fixed hip width apart with a single handle (Figure 9). Inspiration for this design is drawn from the “Bandu basher” cane (Figure 10) which allow for easier use on grass, trails, and other non-paved roads. Our device would improve on the original design by doubling the number of canes (for stability) and adding ultrasonic sensors. Thus, the physical connection with the ground through the skids would transmit changes in ground texture, and an ultrasonic sensor placed on a low cross-beam of the device would detect objects near the ground. The sensor would additionally transmit audio feedback via Bluetooth so that the user could navigate around obstacles.

Figure 10.
The original "Bandu Basher" cane [16].

Idea 3: Three-wheeled Pivoting Cane

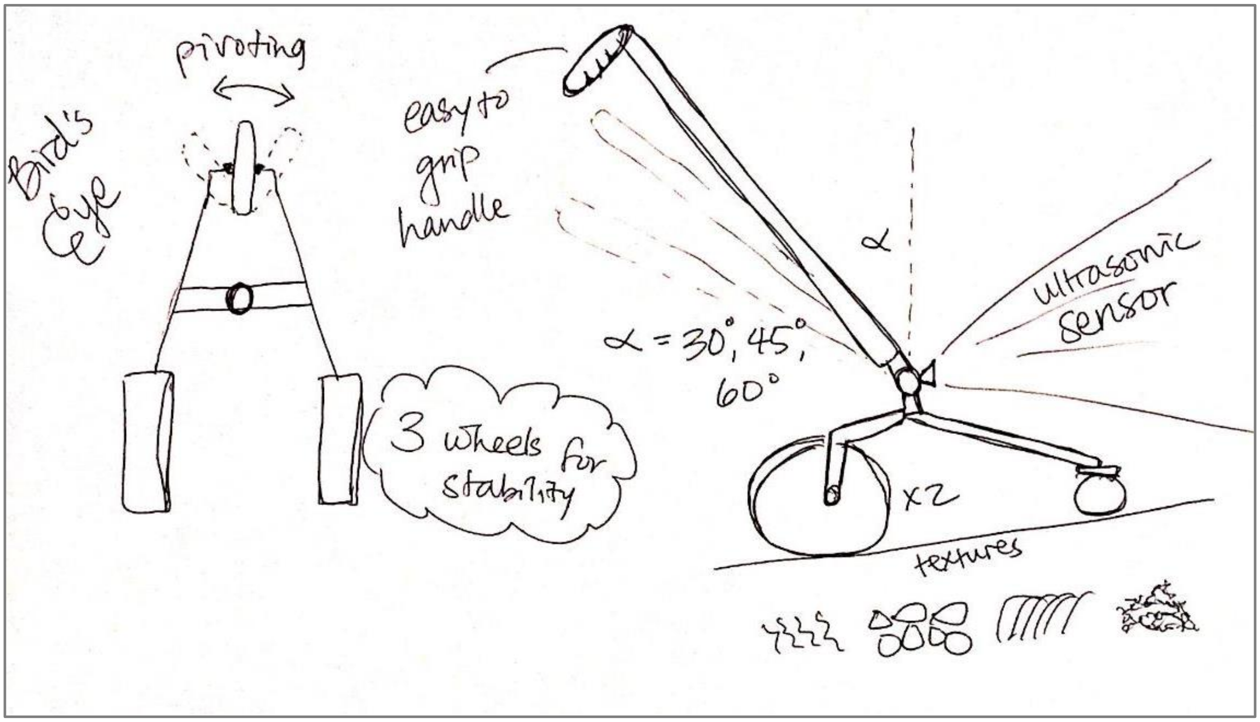


Figure 11.
Three-Wheeled Pivoting Cane with Ultrasonic Sensors and Wireless Feedback (figure drawn by Alyssa Wei).

This simple cane is set on a stable 3-wheel base allowing for transmittance of ground texture information up the cane shaft (Figure 11). An ultrasonic sensor sits near the wheel axles to pick up on low obstacles. Wired vibration motors are fixed to the handle to indicate left, center, right positioning of upcoming obstacles.

Evaluating Design Ideas

Once these three ideas were developed, it became necessary to carefully choose an idea that would both meet our project requirements as well as fit within the given constraints (timeframe, cost, difficulty, etc.). To that end, a decision matrix was created that highlighted the strengths and weaknesses of each of the three ideas in three distinct categories:

Ease of Engineering. This category served as a guide to indicate how difficult the actual design and production of the device would be given current skills and techniques available.

Estimated Cost. This category served as a predictor to the estimated final cost of the device.

Predicted User Acceptance. This category was based on our interactions with Brian, as well as previous research, to help predict aspects of the device that might be beneficial or harmful to the user.

The completed decision matrix is on the following page.

Initial Ideas Decision Matrix

Idea	Ease of Engineering	Estimated Cost	Predicted User Acceptance
Cane-less Lidar Detection	– Difficult to dynamically adjust fit for a variety of user sizes – Difficult to program LIDAR and interpret data	– LIDAR is expensive, upward of $2000	+ "Cool", high-tech device + Users are free from pushing/holding a cane – Does not provide texture feedback from ground – Steeper learning curve to get comfortable with device
Simple Skid Cane	+ The mechanical and electrical systems are within our range of abilities to implement – The interface of mechanical and electrical systems are trickier since a cane-mounted sensor will change sensing direction with user height and gait or arm swing perturbations	– Can be made from cheap or pre-manufactured parts, estimated cost < $50	+ Provides texture feedback from ground + Shallow learning curve if user is used to a white cane – Skis can be more difficult to push across a surface – Skis may provide an excessive amount of direct auditory feedback from ground
3-Wheeled Pivoting Cane	+ The mechanical and electrical systems are within our range of abilities to implement + The interface of mechanical and electrical systems can be engineered to withstand changes in user height and gait or arm swing perturbations	+ Can be made from cheap or pre-manufactured parts, estimated cost < $100	+ Provides texture feedback from ground + Shallow learning curve if user is used to a white cane + Easier to push a cane on wheels than skis

As demonstrated in the above table, iterating on the design of the 3-wheel pivot cane made the most sense as it successfully solved the ease of engineering problem while falling within our budget and time/capability constraints.

Build Methods

Initial Prototyping

Our initial prototype (Figure 12) was developed using readily-available materials such as two-inch insulating foam, duct tape, zip ties, and miscellaneous classroom supplies. In addition, three-inch hard-plastic wheels designed for assistive walker devices were purchased from a typical drugstore and incorporated into the initial prototype. This prototype allowed us to determine optimal wheel placement, sizing for the various components of the device, and axes of rotation. Once we were satisfied with the basic layout of the components, we proceeded to functional prototyping. Additional photographs of this prototype are available in Appendix B.

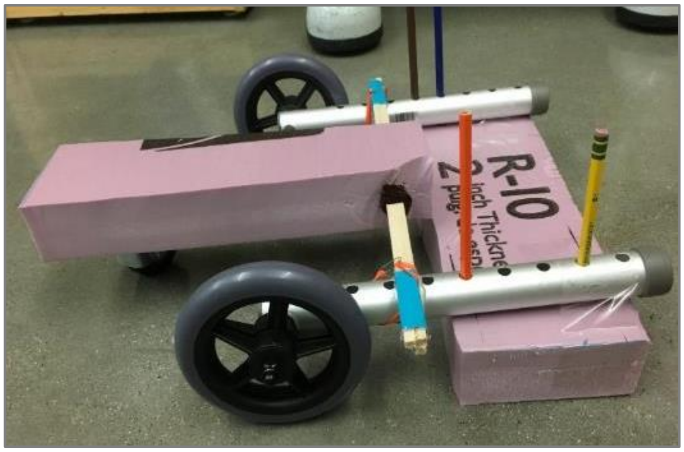


Figure 12.
Initial prototype.

Functional Prototyping

Our functional prototype (Figure 13) was built using a combination of store-bought materials (including a repurposed telescopic handle and caster wheel) as well as eighth-inch Duron board that was cut using a Universal VLS 4.60 laser CAM. This allowed us to produce a custom-built platform upon which we could test and further refine the various mechanical and electrical aspects of the device. Additional photographs of this prototype can be found in Appendix C.

Figure 13.
Functional Duron prototype. This prototype allowed for testing and refinement of the various mechanical and electrical components.

Mechanical Components

Wheels. We initially ordered a wide variety of wheels ranging in diameter (1 to 5 inches), style (pivoting, non-pivoting, swivel ball, caster, simple wheel, etc.), and material (polyurethane, metal, rubber). We then manually rolled the wheels over a variety of surface textures and surface discontinuities carefully noting tactile feel and sound. We wanted to maximize the transmission of important texture feedback from the ground while remaining at an appropriate auditory level. We noticed that the polyurethane wheels mitigated the tactile feelings of unimportant hairline cracks in the ground while picking up on slightly larger tripping hazards and changes in ground textures. These wheels also provided noticeable audio feedback without reaching annoyingly loud levels, especially on pavement and grating. A minimum 5" diameter wheel was required for stability and unimpeded movement over grass, gravel, and other loose materials.

Relative Location of Pivoting Wheel. We were sold on a 3-wheel design because of its balance in regards to stability and maneuverability as seen in our research of strollers and tricycles. Through manual testing of different wheel variations in our initial prototype, we gleaned the following key insights: 1) a single pivoting wheel that is slightly smaller than the non-pivoting wheels provided the appropriately level of maneuverability and weight; and 2) the pivoting wheel, when placed behind the other two wheels, acted as a "keel" to straighten the forward path of the device.

Chassis Size. Once we moved into functional prototyping, we employed a modular design to easily test different widths and lengths of the wheel base. User testing with individuals ranging in height from five feet to six feet indicated that a base 12 inches wide and 18 inches long provided the most stable and smooth platform for all heights.

Axis of Rotation. From the initial sketch, as seen previously in Idea 3 (Figure 11), we have changed the design so that the pivoting handle does not lock at certain angles, but pivots smoothly through 90 degrees of rotation. This design change increased the ease of engineering because we no longer had to implement an angle locking mechanism. It also allows for the handle to dynamically adjust with user height, arm swing, and the bouncing gait of running without affecting how the base contacts the ground. Additionally, the ultrasonic sensors have been placed on a platform between the axle of the front wheels and the pivoting back wheel. This allows the sensors to always remain horizontal to the ground regardless of an incline or decline in the geography.

Electrical Components

Microcontroller. To process the signals from the sensors, an Arduino Uno microcontroller was programmed to serve as a control unit. This small-form-factor device (Figure 14) is essentially an efficient computer that is geared towards interfacing with hardware through onboard inputs and outputs. Thus, we were able to use the Arduino to poll information from the ultrasonic sensors, then perform calculations on the resulting measurements to obtain distances to objects, and feed that information to the motors in the form of pulsed signals to

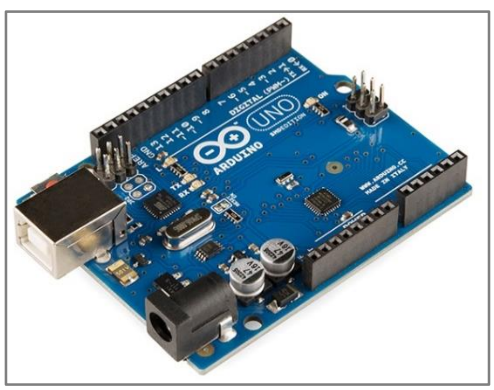


Figure 14.
Arduino Uno Microcontroller [21].

vary vibrational intensity depending on the distance of the detected object (with more intense pulses indicating objects closer to the sensor). A diagram of the wiring schematic is available in Appendix D.

Power. Power to the device is currently provided by a standard 9V battery. Assuming usual drain conditions, this device should run for approximately 8 hours on a single battery charge.

Ultrasonic Sensors. To detect objects in front of the device, a pair of ultrasonic sensors were utilized. These sensors function through echolocation: an emitter sends out a sub-sonic pulse, which then hits an object, and subsequently returns to a collector (the emitter and collector are the two cylindrical silver objects seen in Figure 15). An internal clock on the Arduino measures the time between the sending and receiving of the pulse, and then divides by the speed of sound to obtain the total travel distance of the pulse. Dividing this number in half provides the distance, in inches, of an object detected by the pulse. For optimal positioning, the sensor pairs were placed at six degrees off-center to allow for wide, yet overlapping, fields of view. This number may be adjusted to suit future prototype needs. Calculations and diagrams used for the sensors are available in Appendix E.

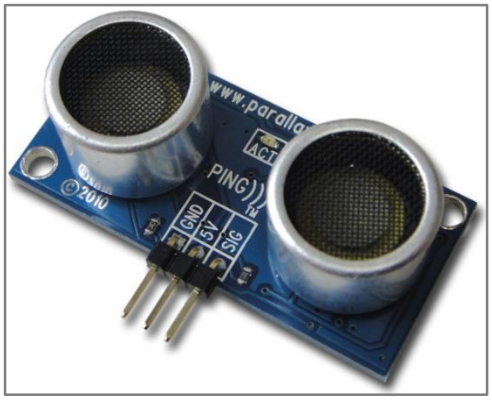


Figure 15.
Parallax PING)))™ Ultrasonic Sensor [21].

Vibrating Feedback. Haptic feedback is given to the user via a pair of vibrating motors (Figure 16). When the Arduino sends the proper signal, these motors will rotate and vibrate with intensity inversely proportional to the distance of the object. Each motor is tied to a sensor, so that when the left sensor detects an object, the left motor will vibrate, and vice versa. If an object is detected across both sensors, then both motors will activate, indicating either a large object ahead, or multiple objects.

Figure 16.
Vibrating motor [21].

Programming Component

Programming for the device was performed using the Arduino Interactive Development Environment and open-source tools. The source code for the sensors and motors can be seen in the Appendix F under "Arduino / Ultrasonic Sensor Code".

Preliminary Testing

Each round of prototypes underwent user testing. Assuming the appropriate levels of functionality, the main concerns for user testing were ease of use and comfort. Members of the design team both used and observed the use of prototypes at various stages. As recommended by the project suggester, we fashioned a pair of excluders by covering most of the surface of safety goggles with black electrical tape so that we could experience using the device with a 5-degree field of vision. The project suggester was also able to test the device at various stages.

Since the initial and functional prototyping determined the optimal design for wheel type, wheel size, device size, and degrees of freedom, user testing checked the height adjustability, ergonomics, and comfort over prolonged use. The main cane shaft was a telescoping rod that could range from 60-112 cm, adequate for user 5 ft to 6 ft in height. Since the shaft pivoted around the front wheels, users could employ a natural arm swing while running without affecting device function.

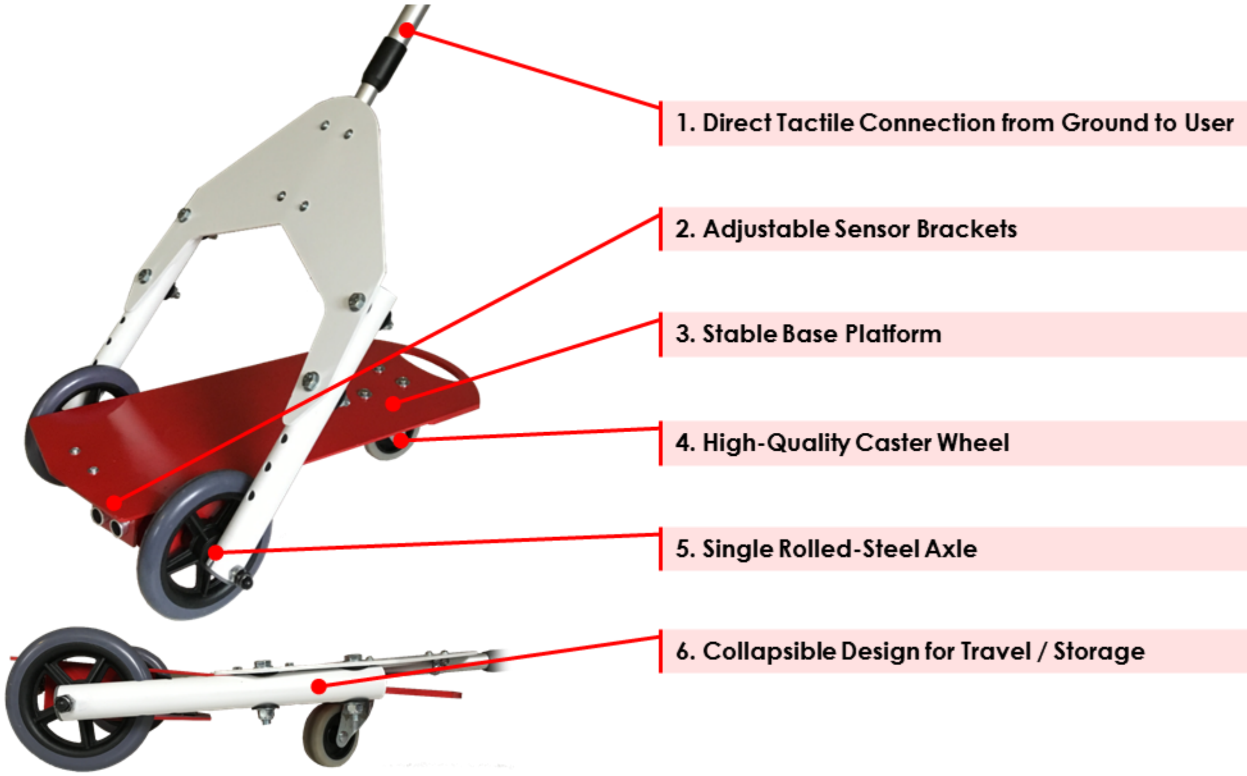
The bicycle handle grip that interfaced with the shaft via ball-socket joints was a later addition and greatly improved user comfort especially over jogs longer than .25 miles. The previous handle which was just a grip on the end of the shaft caused wrist pain due to the awkward angle required to hold it. The new ball-socket joints allowed for 360-degrees of freedom for the direction of the handle and the bicycle grip is molded to fit comfortably in the palm. The bicycle grip is weighted to provide users with greater perceived control of the device without being so heavy that the user gets tired from holding it up. And since much of the device's weight in concentrated near the ground and atop relatively large wheels, the user needs to issue little effort to keep the device moving forward.

We did notice a shallow learning curve when our project suggester tried out our device. Since Brian was used to correcting the navigation errors of his Ambutech rectangular mobility device, which warped and listed sideways, when he applied the same corrections to our device, he found our device swerving as well. As Brian began to put more faith in our device, spending less time looking down at the device and letting the device guide him, we noticed his path straightened considerably.

Current Prototype Results

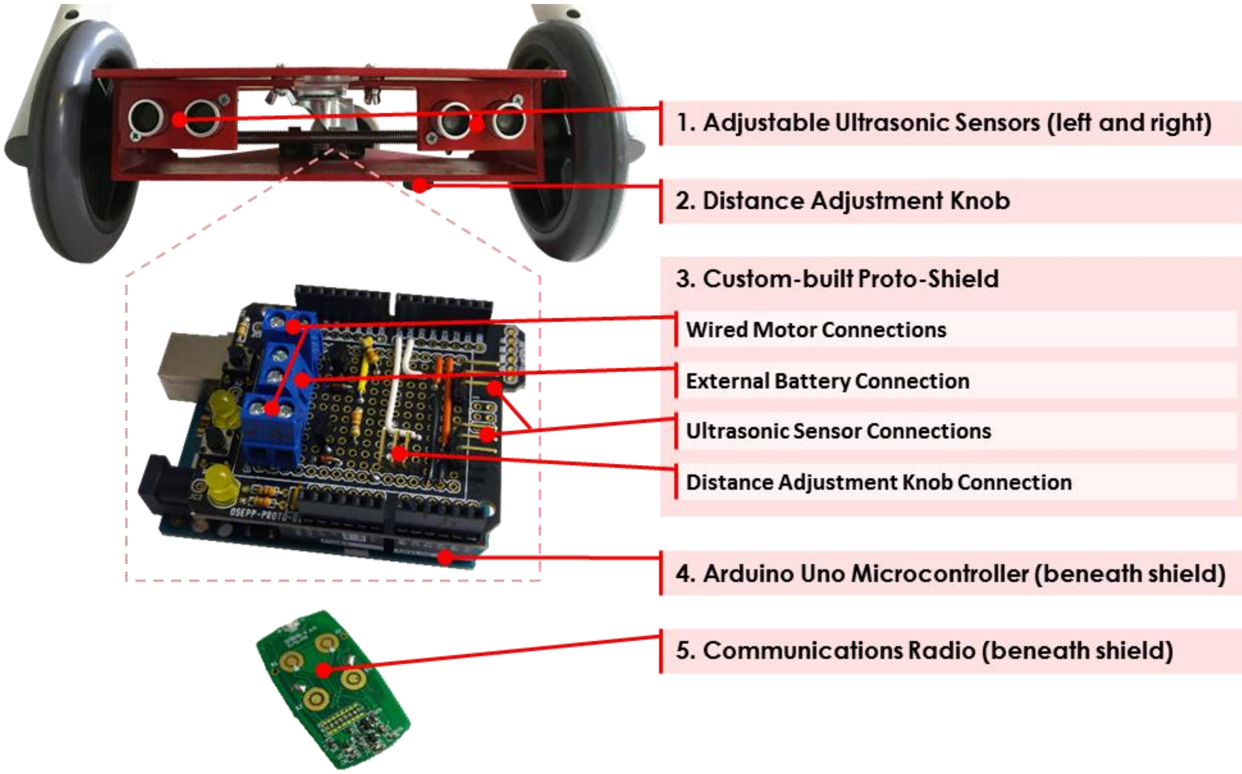
Our iterative design process allowed us to develop a current prototype with the following features:

Mechanical Features



1. **Direct Tactile Connection from Ground to User:** The handle transmits tactile information from the wheels to the user, allowing for immediate feedback on terrain features. The shaft is comprised of telescoping aluminum, which is strong, lightweight, and stiff enough for this purpose.
2. **Adjustable Sensor Brackets:** The angle of the ultrasonic sensor brackets can easily be adjusted through the loosening of a wingnut, allowing the sensors to be set for indoor or outdoor use.
3. **Stable Base Platform:** The design allows the base to always remain parallel to the ground, which in turn keeps the sensors horizontal to the ground for consistent readings. These sensors are then used for advanced warning of upcoming obstacles. Testing with the initial prototype determined that a wheel base of 20 centimeters was optimal, with the third wheel 27 centimeters behind the main axle.
4. **High-Quality Caster Wheel:** A soft-rubber rear wheel allows for smooth operation while acting as a keel, keeping the device traveling in a straight line for both indoor and outdoor use.
5. **Single Rolled-Steel Axle:** A solid axle connects both wheels, allowing them to remain aligned while transferring tactile information directly from the ground, to the wheels and then up to the handle.
6. **Collapsible Design for Travel / Storage:** The device folds flat and locks together with the help of powerful magnets, while an integrated handle allows for ease of transport.

Electrical Features



1. **Adjustable Ultrasonic Sensors (left and right):** Ultrasonic sensors fire in an alternating pattern at four times per second, allowing for rapid detection of upcoming obstacles at distances of up to 3 meters.
2. **Distance Adjustment Knob:** A potentiometer knob is used to set the activation distance of the sensor (the distance at which the sensor will begin reporting vibrating feedback) from 0.2 meters up to 3 meters. This allows the user to set the activation distance to shorter ranges when traveling indoors, or to longer distances when traveling outdoors.
3. **Custom-built Proto-Shield:** A prototyping shield snaps into the Arduino Uno and allows for rapid reconfiguration and modular assembly. The shield contains the following components:
   - Wired motor connections that allow for wired attachment of the left and right vibrating DC motors.
   - An external battery connection for a separate motor power supply (to prevent drawing too much current through the Arduino microcontroller.
   - Ultrasonic sensor connections allow for robust control between the two sensors and the Arduino.
   - A distance adjustment knob connection, which connects to the distance adjustment knob above.
4. **Arduino Uno Microcontroller:** The “brain” of the device, programmed to process and coordinate the various signals and exchanges between all of the device’s components.
5. **Communications Radio:** A simple 315MHz radio transponder sends a latching-style signal to the wrist-mounted vibration pods (not pictured) to control intensity for future wireless implementation.

Ergonomic Features

1. **Lightweight Fatigue-Free Handle:** The vertical component of the device requires only 300 grams to raise the handle, which prevents fatigue during extended periods of use.
2. **Adjustable Telescopic Handle:** The lightweight shaft is able to adjust and lock from 60 cm to 112 cm.
3. **Removable Double-Ball Pivoting Joint:** This joint allows for 3-axis adjustment, providing the handle with unlimited lockable positions. In addition, the handle is threaded directly into the shaft, allowing it to be removed or re-attached without the need of tools.
4. **Soft Ergonomic Grip:** A soft rubber grip eases fatigue during jogging and prevents cramping of the hand during extended periods of use.
5. **Large Horizontal Base Platform:** The large base provides over 800 square centimeters of horizontal space, which can be used for storage or additional sensor placement.

Aesthetic & Protective Features

Since the white cane (with or without a red tip) is a legally recognized device for granting right of way [14] , we chose to color our prototype in a similar fashion. This allows pedestrians to acknowledge the presence of a user who is visually impaired without embarrassing questions. In addition, several coats of primer, pigment, and clear coat protect the device from the elements, allowing it to be wiped clean and providing it with a more polished and professional appearance.

Software & Electrical Component Optimization

The major reason for incorporating electrical capabilities is to provide advanced warning of obstacles. The electrical components (ultrasonic sensors and wired vibrational feedback) did not undergo as much revision as the mechanical components, however modifications were made to increase the energy efficiency of the vibrating motors. Additionally, a knob / potentiometer was added to the base of the device to scale the sensor sensitivity, providing longer range sensing for outdoors and shorter range sensing for indoors. On the software side, code was optimized to run faster and allow for sensor scaling and to ensure the device did not draw too much current from the Arduino at any one time (to prevent shorts and to optimize battery life). The updated code can be seen in Appendix F. Feedback concerning the electrical components from a variety of testers of different ages, body types and disabilities was unanimously positive.

Cost

As mentioned in the introduction, approximately 90% of the world's visually-impaired population live in low-income settings. As such, it was our goal to keep the price of the device as low as possible and relatively simple to reproduce on a wider scale. Table 1 below indicates the components used to produce the current prototype and their retail costs. Note that a finalized version would have a lower cost due to scaling, better component sourcing, and optimized production methods.

Table 1: Current Prototype Costs

Item	**Source**	**Quantity**	**Per Unit**	**Total Cost**
Duron board (18 x 24 inches)	Stanford PRL	1	$3.00	$3.00
OSEPP Ultrasonic Sensors	Fry's Electronics	2	$5.99	$11.98
Arduino Uno Microcontroller	Fry's Electronics	1	$19.99	$19.99
Arduino Prototyping Shield	Fry's Electronics	1	$10.99	$10.99
Miscellaneous Wiring	Fry's Electronics	1	$4.99	$4.99
Potentiometer & Knob	Fry's Electronics	1	$2.99	$2.99
5V Power Supply	Fry's Electronics	1	$6.99	$6.99
Schwinn Comfort Grip	Amazon.com	1	$9.99	$9.99
Double-Socket Arm	Amazon.com	1	$7.99	$7.99
5" Walker Wheels	Walgreen's	1	$10.85	$10.85
3" Caster Wheel	Home Depot	1	$2.85	$2.85
Miscellaneous Mounting Hardware	Home Depot	1	$7.00	$7.00
			Total Cost	**$99.61**

Safety

Currently, the only safety concerns with the device are due to its prototype status. Particularly, a further prototype would implement a waterproof enclosing to protect the circuitry and electrical components.

Despite this, the current prototype operates at low voltages and currents, so there is no risk of shock or danger to the user.

Reliability and Safety

While the addition of electronic components may seem to limit the usage time of the device, they are actually capable of running for over ten hours on a single charge. In addition, the device can be charged with a standard Micro-USB adapter, similar to those used in charging cell phones and other consumer electronics.

As for safety considerations, mechanically, this device does not pose a greater risk than a white cane. Electrically, the voltage (5V) and current (<100 mA) are low enough that shorts due to rain or wear-and-tear on wires, while damaging to components, are not harmful to the user.

Discussion

Challenges & Potential Solutions

Most the of the challenges/future work lies in the electronic half of this prototype; for the most part, the last prototype made could mechanically be a conceivably marketable device. The only major area where change might be necessary would be in the collapsibility of the cane. While we like the sturdiness of the handle and the fact that it can be collapsed at all, it is still too large to comfortably fit in tote bag or something similar without sticking out. Therefore, a second way of folding the rest of the cane down so that it is no longer than the length of the base when fully collapsed is something to consider.

As mentioned previously, the electrical components provided a few challenges. While many canes with sensors exist on the market, many use more specialized (and therefore expensive) components than would fit within our budget. We had to develop a system that would provide the user with adequate information about his surroundings, but do so using commonly available electronic components. We also had to design the system to prevent false positives that could occur from too many ultrasonic sensors, but still differentiate between the location of different objects successfully. In addition, we required the sensors to stay relatively parallel to the ground, which necessitated a swiveling component of the physical structure.

Another major challenge was relaying the information from the sensors back to the user. We want to be able to differentiate between a singular central object detected by the two sensors or two peripheral objects detected by the two sensors (so, for example, having a left-right system that both went off with an object in the middle wouldn't work, since it could indicate either an object to the center or some combination of multiple objects). Currently, the code attempts to solve this problem by activating both vibrating motors in tandem when a singular central object is detected, or alternatingly pulsing the vibrating motors when two different peripheral obstacles are detected. Testing on these feedback schemes is ongoing.

Next Steps

We are very pleased with the final prototype that we developed for this quarter-long project. While the device met all of the goals that we had set for ourselves, there are still aspects of the device that can be improved. First, we need to create a more reliable wireless system, as the system in its current form is prone to signal lag issues. Second, we need to find a better power supply, as the one we currently use is faulty and failed after a few minutes of use. Third, a shell for the bottom of the device would be necessary, both to act as a skid plate and to house the electronics properly. Lastly, we want to consider other potential markets for the device, such as for children learning to navigate with a cane. With the addition of things like fun noises, lighting effects, or modification to the vibration relay, the device could be a more enjoyable method of learning to use assistive technologies for children.

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- The teaching assistants at the Stanford Product Realization Lab and Room 36.
- Our fellow students and community guests.

Project suggester Brian Higgins with the functional prototype.

References

[1] T. Bickford, "Care and Feeding of the Long White Cane: Instructions in Cane Travel for Blind People," *Future Reflections: The National Federation of the Blind Magazine for Parents and Teachers of Blind Children*, pp. 13-32, Winter 1996.

[2] American Academy of Orthopedic Surgeons, "How to Use Crutches, Canes, and Walkers," February 2015. [Online]. Available: http://orthoinfo.aaos.org/topic.cfm?topic=A00181. [Accessed 13 March 2016].

[3] World Health Organization, "Visual Impairment and Blindness," August 2014. [Online]. [Accessed 3 March 2016].

[4] Achilles International, "Overview: Achilles International," [Online]. Available: http://www.achillesinternational.org/programs/overview. [Accessed 2 March 2016].

[5] E. O. F. M. P. A. Ann Hallemans, "Low Vision Affects Dynamic Stability of Gait," *Gait & Posture*, vol. 32, no. 4, p. 547–551, 2010.

[6] VisionAware: American Foundation for the Blind, "What Type of Cane Should I Use?," 2015. [Online]. Available: http://www.visionaware.org/info/everyday-living/essential-skills/an-introduction-to-orientation-and-mobility-skills/what-type-of-cane-should-i-use/1235. [Accessed 12 March 2016].

[7] American Council of the Blind, "White Cane Laws for States," 24 October 2013. [Online]. Available: http://www.acb.org/whitecane. [Accessed 6 February 2016].

[8] Ambutech, "Rectangular AMD," Unknown. [Online]. Available: https://ambutech.com/shop-online/rectangular-amd. [Accessed 16 February 2016].

[9] IITDelhi, "SmartCane," Unknown. [Online]. Available: http://assistech.iitd.ernet.in/smartcane.php. [Accessed 16 February 2016].

[10] Sound Foresight Technology, Unknown. [Online]. Available: https://www.ultracane.com/. [Accessed 16 February 2016].

[11] T. Lewis, "Seeing-Eye Vest? Vibrating Clothing Helps Blind Navigate," 14 November 2014. [Online]. Available: http://www.livescience.com/48760-vibrating-vest-blind-navigation.html. [Accessed 16 February 2016].

[12] DesignBuzz, "GPS Navigation Devices to Guide the Visually Impaired," 14 April 2012. [Online]. Available: http://www.designbuzz.com/10-gps-navigation-devices-guide-visually-impaired/. [Accessed 16 February 2016].

[13] J. D'Onfro, "How Google Glass Helped This Blind 13-Year-Old Dancer Get His Vision Back," 24 November 2014. [Online]. [Accessed 3 March 2016].

[14] American Council of the Blind, "White Cane Laws for States," 24 October 2013. [Online]. [Accessed 8 March 2016].

[15] M.-L. Nguyen, "Blind/visually impaired runner and his guide at the 2014 Paris Marathon," 6 April 2004. [Online]. Available: https://commons.wikimedia.org/wiki/File:2014_Paris_Marathon_t083553.jpg. [Accessed 16 February 2016].

[16] "Bundu Basher," [Online]. Available: http://www.sauerburger.org/dona/bundu. [Accessed 14 March 2016].

[17] Western Blind Rehabilitation Center, "WBRC Team Completes the 100th Annual Bay to Breakers Race," 17 May 2011. [Online]. Available: http://westernblind.blogspot.com/2011/05/wbrc-team-complete-100th-annual-bay-to.html. [Accessed 13 March 2016].

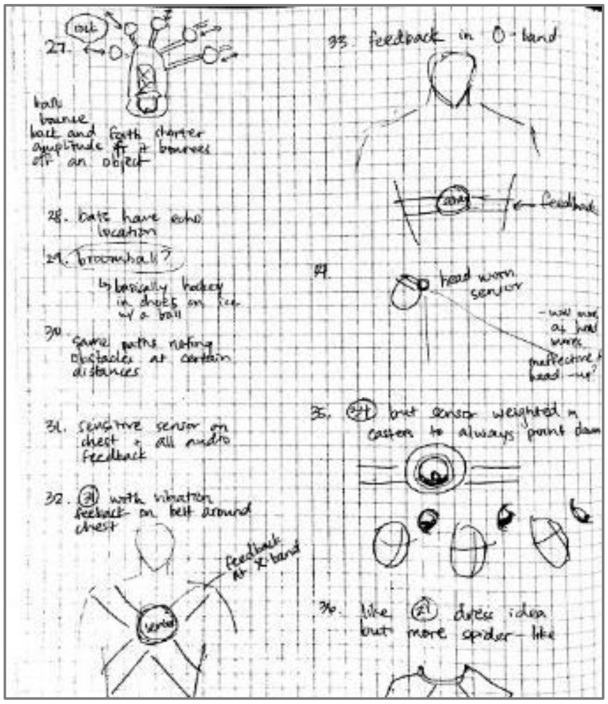
[18] Health Mark, Inc., "Alumilite Silver Walking Cane," 2015. [Online]. Available: http://www.healthmarkinc.net/product/alumilite-walking-cane/. [Accessed 13 March 2016].

[19] K. Barry, "Wired," 2 February 2009. [Online]. Available: http://www.wired.com/2009/02/lightlanes-lase. [Accessed 2 February 2016].

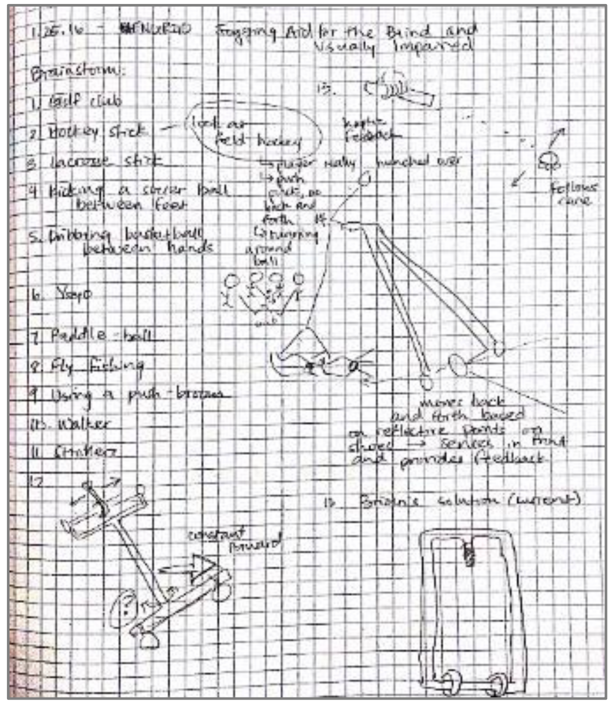
[20] "RobotShop Online Store," 2016. [Online]. Available: http://www.robotshop.com/en/corporate/about. [Accessed 2 February 2016].

Appendix A: Early Brainstorming Sketches

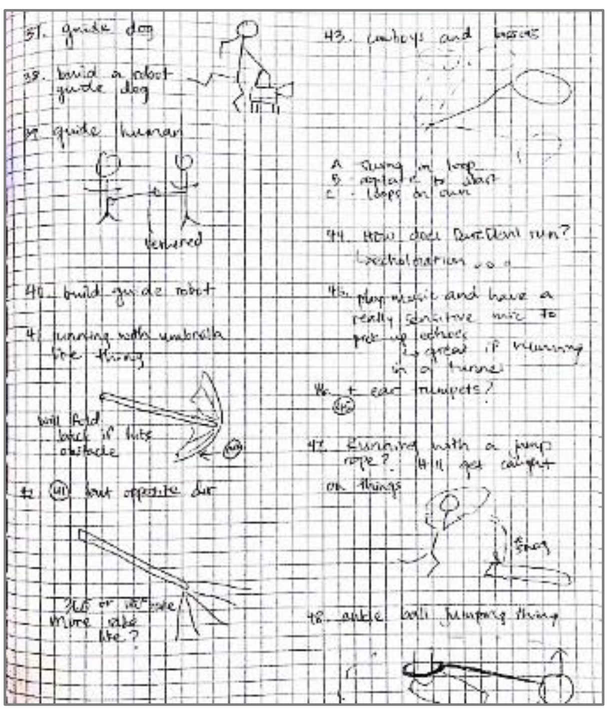
The following photos show sketches of early ideas that were brainstormed. The drawings include various wearable technologies and cane or cane-like mechanisms using a variety of sensors (LIDAR, IR, ultrasonic) with wired and wireless systems utilizing audio or vibratory feedback.



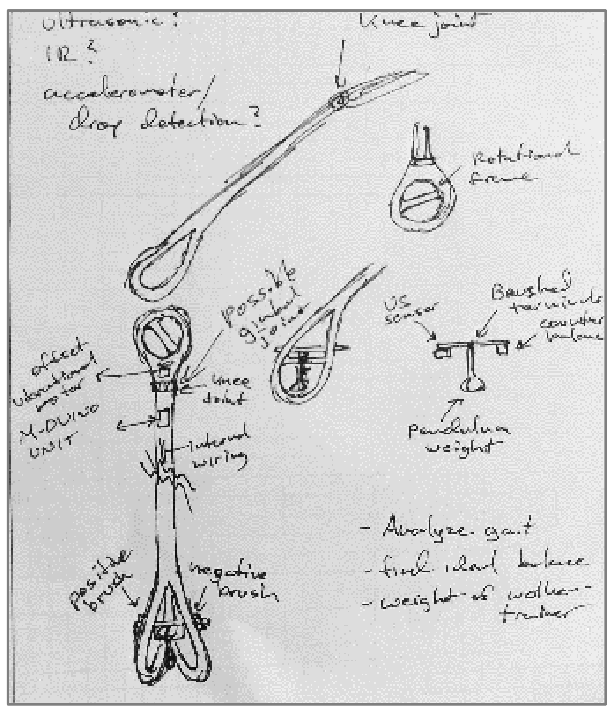
Sketches of early wearable device designs.



Sketches of early rolling cane designs.



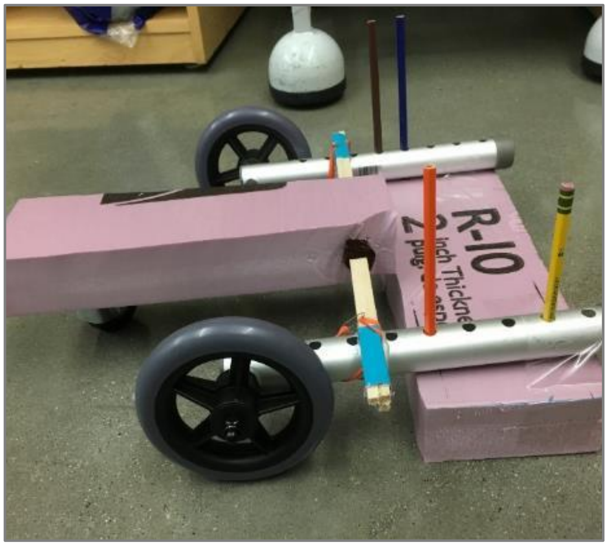
Sketches of early enhanced cane designs.



Sketches of early enhanced skid cane designs.

Appendix B: Additional Photographs of Initial Prototype

The following two pictures show early prototypes using 2-inch pink foam, repurposed purchased items and school supplies. These prototypes allowed us to test the stability and proportions of the base as well as a number of pivoting axes.

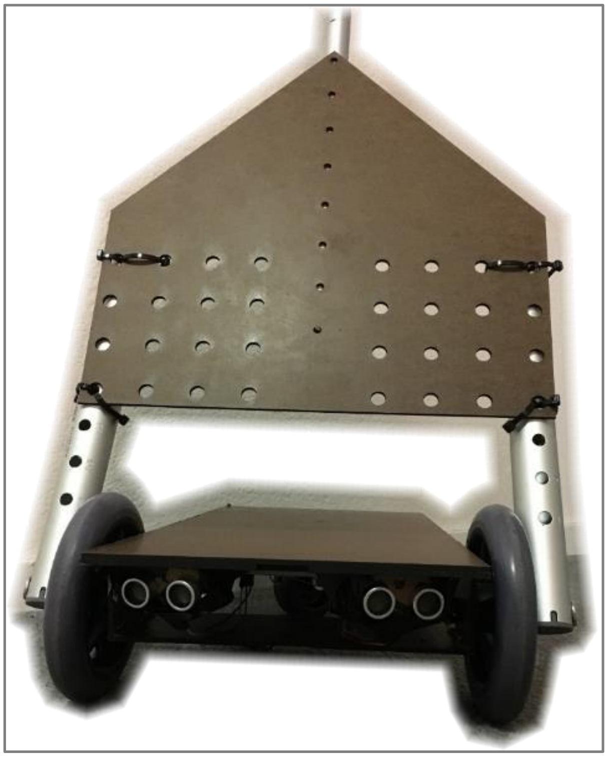


Initial prototype in a horizontal configuration.

Initial prototype in a vertical configuration.

Appendix C: Additional Photographs of Functional Prototype

These photos show different views of the functional prototype made of laser cut 1/8” Duron and repurposed items (handles, wheels, etc.). This prototype possessed functional mechanical and electrical components that allowed for intensive testing. Further improvements to this prototype were mainly aesthetic or to improve ergonomics and transportability.



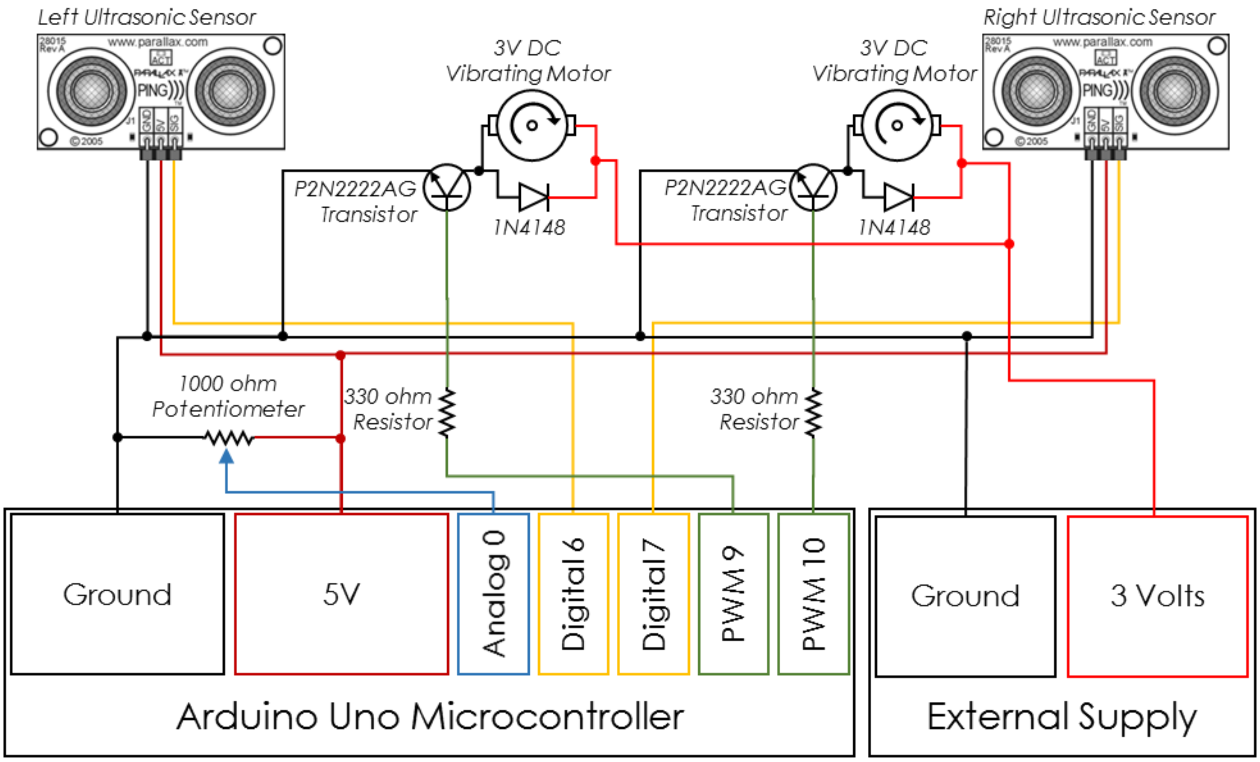
Front view of functional prototype with sensors.

Side view of functional prototype with main axle.

Complete view of functional prototype.

Appendix D: Electronics Wiring Diagram

The following diagram illustrates the connections within the device. A separate power supply was required for the wired version to provide two different voltages, but a further prototype would fully incorporate the wireless capabilities discussed previously.

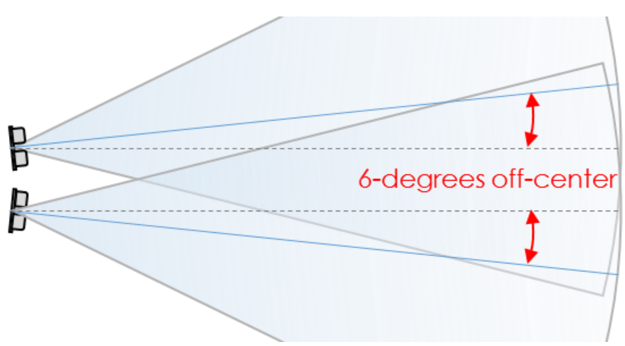


Appendix E: Sensor Calculations

In order to convert the sensor readings into useful measurements, the following equation was used:

$$\frac{Pulse\ Travel\ Time}{Speed\ of\ Sound} \times \frac{Total\ Distance}{2} \rightarrow \frac{\left(\frac{t}{340.29\ \mathrm{m/s}}\right)}{2} = Distance\ (in\ centimeters)$$

In addition, the diagram at right was used to determine optimal sensor placement based on both manufacturer values and measured values. These allowed us to determine that at the maximum range of 3 meters, an offset of six degrees would create three detection zones: left, center (due to overlapping detection fields), and right.



Appendix F: Code for Object Detection and Vibration Feedback

```
/* Written by Thomas Trzpit for ENGR 110 (Winter 2015-2016)
 *
 * Pin Assignments / Wiring
 *   Component       Part         Arduino
 *   Sensor Left     SIGNAL       Pin 6
 *                   5V           5V
 *                   GND          GND
 *   Sensor Right    SIGNAL       Pin 7
 *                   5V           5V
 *                   GND          GND
 *   Motor Left      3V           Pin 10
 *                   GND          GND
 *   Motor Right     3V           Pin 9
 *                   GND          GND
 *   Potentiometer   5V           5V
 *                   GND          GND
 *                   Sweeper      Analog Pin 0
 */

/*
 * Pin Constant Declarations
 */
const int pingLeft   =    6 ;
const int pingRight  =    7 ;
const int leftMotor  =   10 ;
const int rightMotor =    9 ;
const int rangePin   =    0 ;
const int maxSpeed   =  255 ;

/*
 * Global Variable Declaration
 */
Int  rangeValue ,
     leftSpeed ,
     rightSpeed ,
     delaySpeed = 200 ;
long durationLeft ,
     durationRight ,
     inchesLeft ,
     inchesRight ;

/*
 * Program Initialization
 */
void setup () {

  // Pin mode settings
  pinMode (  leftMotor , OUTPUT ) ;
  pinMode ( rightMotor , OUTPUT ) ;
}
```

```
/*
 * Main program loop
 */
void loop () {

  // Disable current draw for motors
  analogWrite ( leftMotor , 0 ) ;
  analogWrite ( rightMotor , 0 ) ;

  // Pull potentiometer value to set range sensitivity
  getRangeValue () ;

  // Pull sensor readings
  delay ( delaySpeed / 2 ) ;
  pingLeft () ;
  delay( delaySpeed / 2);
  pingRight () ;

  // Convert reading to inches
  inchesLeft = microsecondsToInches(durationLeft);
  inchesRight = microsecondsToInches(durationRight);

  // Conditional statement to activate vibrational motor
  if ( inchesLeft <= rangeValue ) {
      leftSpeed = map ( inchesLeft , 0 , rangeValue , maxSpeed, 0 ) ;
      analogWrite(leftMotor, leftSpeed);  // set the new speed
      delay(delaySpeed );
  } else {
      analogWrite(leftMotor, 0);  // set the new speed
  }
  analogWrite(leftMotor, 0);  // set the new speed


  if ( inchesRight <= rangeValue ) {
      rightSpeed = map ( inchesRight, 0 , rangeValue, maxSpeed, 0 ) ;
      analogWrite(rightMotor, rightSpeed);  // set the new speed
      delay(delaySpeed );
  } else {
      analogWrite(rightMotor, 0);  // set the new speed
  }
  analogWrite(rightMotor, 0);  // set the new speed
}
```

```
/*
 * Helper Functions
 */

// Fire left ultrasonic sensor
void pingLeft () {
  pinMode(pingLeft, OUTPUT);
  digitalWrite(pingLeft, LOW);
  delayMicroseconds(2);
  digitalWrite(pingLeft, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingLeft, LOW);
  pinMode(pingLeft, INPUT);
  durationLeft = pulseIn(pingLeft, HIGH);
  pinMode(pingLeft, INPUT);
}

// Fire right ultrasonic sensor
void pingRight () {
  pinMode(pingRight, OUTPUT);
  digitalWrite(pingRight, LOW);
  delayMicroseconds(2);
  digitalWrite(pingRight, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingRight, LOW);
  pinMode(pingRight, INPUT);
  durationRight = pulseIn(pingRight, HIGH);
  pinMode(pingRight, INPUT);
}

// Convert sensor reading to inches
long microsecondsToInches ( long microseconds ) {
  return microseconds / 74 / 2;
}

// Convert sensor reading to centimeters
long microsecondsToCentimeters ( long microseconds ) {
  return microseconds / 29 / 2;
}

// Pull range sensitivity settings
void getRangeValue() {
  rangeValue = analogRead ( rangePin ) ;
  rangeValue = map ( rangeValue , 0 , 1024, 20, 108 ) ;
}
```