Project 5 –Assistive Awareness Apparatus for the Blind

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EDD 104: Engineering Communications II: Section 61

Presentation Link: Assistive Awareness Apparatus for the Blind Final Presentation

Executive Summary - Jake

Design Problem: The blind are at a significant disadvantage when it comes to perceiving their environments. One popular current solution is a white cane that is swept in front of the user to determine if there are hazards. Overtime, this has become outdated and is due for a technological upgrade. The white cane is, on average, 36 inches long. This means that the blind can only anticipate objects within this reach. As technology has advanced, the possibility for providing more feedback than the limits of the white cane has increased. The white cane also invades the privacy of the user as, when they use it, they are instantly labeled as blind to everyone around them. It is estimated that only 8 percent of blind people in the US use a white cane for these reasons.

Design Solution: The proposed assistive awareness apparatus collects information about the environment and then relays it to the user. It consists of a gyroscopic camera, ultrasonic sensor, phone application, machine learning technology, clip, and audio/vibration cues. The camera and sensor work in parallel to observe any potential hazards. Due to its wide lense and gyroscopic functionality, the camera provides all visual based information to the phone application. The sensor uses waves to determine an accurate estimation of how far away hazards are. This information is sent, through bluetooth, to the user's smartphone where it decides what should be done next. Through vibrations in the smartphone and audio via bone-conducting headphones, the user is informed about any possible hazards and other useful information. Both the camera and the sensor are attached to the shoe of the user by a flexible clip. This clip is custom for the size of the user and will fit on just about any shoe. If the camera or sensor needs to be adjusted, the app will recognize this and inform the user. In addition to detecting hazards, the device includes features that make using it a satisfying experience. It includes a GPS, tutorial, Text-to-speech software, machine learning, and Screen Reading.

Design Assessment: The device provides a more effective solution to help the blind than the white cane. It is far more inconspicuous due to its ideal placement on the user's body. Very few people will be looking down at the shoe of a person. This ensures that the user can keep their blindness personal if they wish to do so. Also, it has a further range than the white cane. The utilization of both a camera and an ultrasonic sensor makes it more accurate than the white cane which is less intuitive and more prone to human error. The built-in tutorial ensures the user is fully trained and informed about the device's features before they implement it in their everyday lives. Bone-conducting headphones allow users to hear both their environment and the device's instructions clearly. GPS technology saves routes the user is comfortable with and prevents the user from getting lost.

Conclusion: The privacy and independence of the blind would be increased. Accidents caused by human error while using the white cane would be eliminated. By using bone-conducting headphones and vibration, the device does not impede on remaining eyesight or other senses. The device utilizes technological features absent from alternatives including GPS, Screen Reading, text-to-speech and machine learning.

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Design Problem Kali, Evan

Introduce Background - Kali

Many blind and visually impared people are identified by their use of a white cane, an object used to find obstacles in someone's surroundings. It is challenging to navigate their surroundings because human society is set up in preference of the sighted, so daily tasks become harder for this group of people. The white cane is the most well known navigation device for the blind but does not have in depth feedback for the user. There is no way to identify what the object is to the user therefore it becomes inconvenient to use. The cane is not as helpful as one may think, becoming a hassle to use as well as being an obvious indicator of being blind. Some may find this as comforting but others find that it is uncomfortable for a stranger to know they are blind or visually impared. Having a better alternative to the white cane for the blind would allow for a less noticeable design. Those that are uncomfortable can now choose to tell someone if they are visually impared. With a better design it is also possible to create better feedback than the white cane so users know what the obstacle is in their path.

Design Statement - Kali

Design an inconspicuous device that provides a way for the blind to identify their surroundings.

Introduce System level requirements - Evan

The development of the device was guided by four requirements as outlined by the Project CEO. These requirements were as follows: The device shall warn the user of trip hazards and ground conditions, the device shall provide a way for the user to identify their surroundings to relay more information than a white cane can, The device shall be inconspicuous to those around the user, and the device shall be less cumbersome than a white cane.

Explain/define subsystem level requirements - Evan

Using the aforementioned device requirements, three subsystem topics were created to further define the parameters of the device. The 'Structure' subsystem requirements define the device's physical characteristics, such as its weight and appearance. The device's performance and function are defined within the 'Function' subsystem requirements, outlining the methods by which the user will receive information and how far the device can detect hazards. The final subsystem, 'User-Interface,' defines the ease of use of the device regarding the interaction between the device and the user.

Reference appendix A - Evan

All of the previously mentioned requirements, as well as the subsystem requirements, can be found within Appendix A.

Evaluation of Design Concepts

Introduce Evaluation criteria - Mary

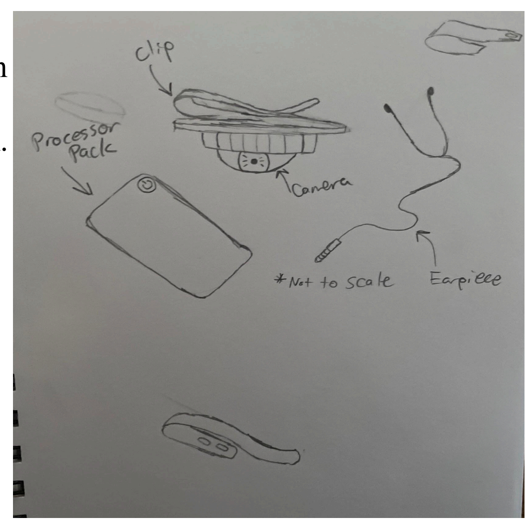
Safety:

Seeing as the device is intended to almost completely replace the sight of a blind user, the safety of the device must effectively detect danger for the user to avoid. We decided to accordingly assign this criterion the highest weighting factor of .25.

Reliability:
Since it would be hard for a blind user to know whether the device was malfunctioning until too late, the device was chosen with reliability as a high weighting factor of .2.
Ergonomics:
There is already so much complication in a blind person's everyday life, so we knew that our device should be as seamless a transition as possible for the user. We gave ergonomics a weighting factor of .2.
Style:
The description of our project was to create a device that was "inconspicuous," so we knew we had to take the style of the device into account, making sure it was at least less noticeable than the common white cane. We gave style a weighting factor of .15.
Cost:
Cost is always an important thing to consider when designing a device so as to make it accessible to more people. However, we felt that people would not mind spending more money than the cost of a white cane since our device would be such an improvement from it, so we made the weighting factor .1.
Requirements:
We had established several requirements that had to be satisfied in our final design, as is customary in product development. This was how we were able to focus our brainstorming. We gave this criterion a weighting factor of .1.

Viable Concept 1 - CamClip Evan, Zack

The 'Cam-Clip' is a Sensory Substitution Device (SSD) that can be attached to the user's clothing to provide a view of the ground to sense the changes in topography. It will warn the user of various hazards that may be present on the ground around them. For example, the camera would be able to see the first step in a stairwell as a change in ground elevation, so it would then consequently warn a blind person of a stair sized jump in terrain levels. The device processes the information gathered by the camera using an external processor pack. After processing, the pack then relays data to the user through the use of audio cues transferred via the connected earphones. The camera is attached to a visor clip to provide the user with options regarding where they may attach the device. Examples include clipping the camera to a hat, a shirt, a belt, or a pocket. All of the aforementioned design components can be seen in the figure to the right. Referring to the image on the right, the processor pack will be pocket sized and will have a headphone outlet to use the earpieces, also shown.

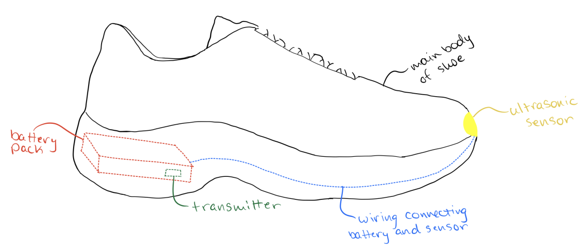


Please note that the drawings are not to scale. The viable design fulfilled all Device Requirements which may be found in Appendix B. The device would alert the user of trip hazards and ground conditions through the processing and transmission of visual data as audio information for the user to understand. It would give more information than a white cane, as it would be seeing a larger range of surrounding terrain than a white cane would make contact with per swing. Relative to a white cane, the device is much smaller and is rather inconspicuous.

Lastly, the device is significantly smaller and more lightweight than a white cane. This, coupled with the fact that the CamClip would be a hands free device, makes the viable design far less cumbersome than a white cane. To judge how well the design satisfied the determined evaluation criteria, the Evaluation Matrix was used (see Appendix A). Each member of the group, excluding those who made the design, filled out a score between one and three for each criteria.The average of these values were then inserted into the Evaluation Matrix. These average scores were between 2 and 3 for every criteria on the list except for style. This resulted in a final weighted score of 2.30, which was the highest score across the three designs. This, however, did not mean that the group was simply going to use this design. Instead, it was decided that we would compile the best aspects of each of the three designs to make the best final design possible. While discussing components of the CamClip viable design to be brought into the final product design, the clip style was altered so that it may be more fulfilling with respect to the style requirement. The final clip will be fixed to the individual's shoe, while the topography reading camera will remain unchanged aside from where it will be mounted. Instead of being attached to a shoe via a clip, the camera will sit on a sturdy strap that secures itself around the user's shoe. Additionally, a smart phone application will be used to process and transfer data instead of an external processor pack. The user will still use an earphone to receive information, however it will be through a wireless connection. The earphone will also be bone conducting, so it should not deter the user from using their sense of hearing. Ultimately, the CamClip's best feature, being the hands-free topography sensing camera, was brought into the final design, while other features were reworked and combined to form the final design for the Sensory Substitution Device.

<u>Viable concept 2 - Shoe Mary, Kali</u>

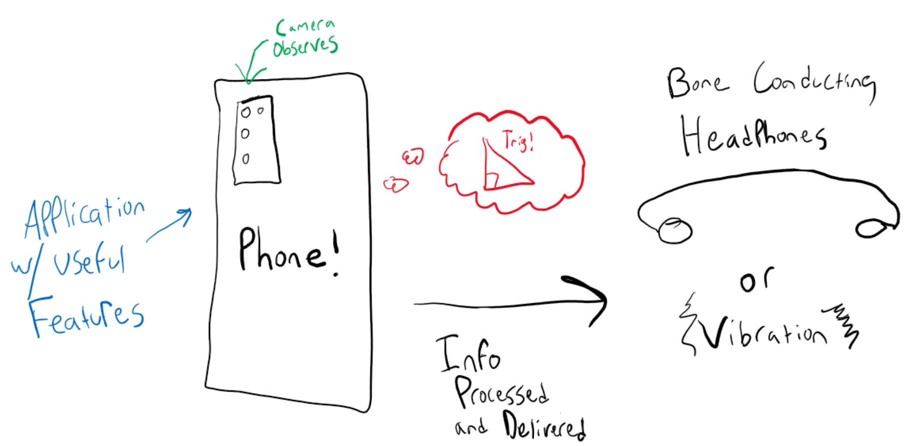
The "Ultrasonic Shoe Sensor" device utilizes an everyday object, a shoe, to communicate to the blind if there is an obstacle in their way. An ultrasonic sensor is placed at the toe of the shoe while wiring is run through the bottom of the shoe to the battery pack and transmitter, which is all hidden within the rubber of the shoe and can be seen in the figure to the right. An ultrasonic sensor works by sending out waves and using the time it took for the wave to get back to calculate how close or far something is from it. This device uses this technology to warn the user of obstacles. The device transfers information from the ultrasonic sensor through the wires in the shoe to change the language through the transmitter, which then lets out patterned pulses for the user in the heel of the shoe. The patterns that would be played are different depending on the distance the user is from the obstacle, conveying how urgent it is for the user to react accordingly. This device remains inconspicuous because there is only a small portion of it visible from the outside of the shoe, and the seen portion is still inconspicuous considering that it is on a shoe, not noticeable unless pointed out. All of our system level requirements are satisfied by this viable design. It "warns the user of trip hazards and ground conditions" (see Appendix B) by detecting them with the ultrasonic sensor and then sending the signals to the transmitter to trigger the vibrational pulses in the heel of the shoe. It provides a way for the user to "identify their surroundings to relay more information than a white cane can" (see Appendix B). We improved upon the white cane in this aspect by allowing the system to more specifically identify the obstacles. The

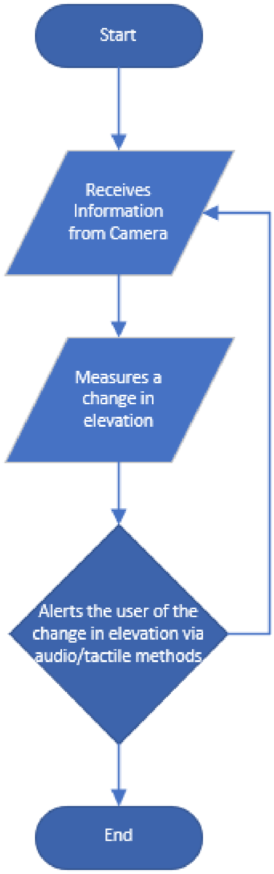


differing vibrational pulse patterns also help improve reliability of the device. It also satisfies the system level requirement stating that it “shall be inconspicuous to those around the user” (see Appendix B) by being placed on the shoe, a part of a person that is not as obvious to onlookers. The device is also much “less cumbersome than a white cane” (see Appendix B), as it is located only on the shoe of the user and requires no handheld components for operation. After presenting our design, it was then scored by each member of the group in the evaluation matrix (see Appendix A), based on how well it covered the previously determined evaluation criteria for our project. The ultrasonic shoe sensor obtained a weight score of 2.23 out of 3, with the best qualities of style and requirements. This design ended up having the lowest score of the three viable concepts, but when the group talked about its qualities, it was decided that having the detection method at the shoe level was the best option for aiding the blind in navigation. The use of an ultrasonic sensor along with the placement of the device on a shoe were incorporated into the final design. What was changed was the addition of a camera mounted on the shoe(see viable concept 1), the fact that the user now receives warning of the obstacles through a phone app (see viable concept 3), and the use of bone conducting headphones that convey audible cues to the user to compound the vibrational cues from the smartphone.

Viable concept 3 - Application Matthew, Jake

The smartphone application, or “electronic cane”, is a device that utilizes the user’s smartphone camera to gather information about the environment and communicate the information to the user. The information provided by the camera is processed using trigonometric calculations to determine changes in elevation and any abrupt hazards in the user’s path. The phone camera needs to be pointed straight in front of the user and slightly downward. It is able to tell the user, through audio and vibration, when they need to move the camera to maximize the experience. The application includes a tutorial for the user to limit the amount of training time the user would need in order to use the device. The tutorial trains the user with the device so that when they are ready to implement it into their everyday lives, they are fully prepared to do so.The application will use audio and vibrations to communicate all information to the user. For all audio cues, the message will be sent to the user through bone conducting headphones. These headphones are placed around the ear, as opposed to inside of the ear, ensuring the user can still hear their normal environment clearly. Additionally, it is important to note that the use of a smartphone does not impede on any remaining eyesight the user may have. Using existing software that converts text to audio, the app will be able to read text to the user. When the camera is pointed at signs, the camera recognizes the words and reads them aloud to the user. This feature is similar to what can be seen in translation apps that use a camera to translate words into different languages. The device will also have GPS location features, including the storage of locations and calculating quick and safe routes for the user. This allows the user to make sure they are taking a route they are comfortable with and avoid making directional errors. The device will feature machine learning, the development of artificial intelligence without explicit instructions, to recognize different objects and relay these objects to the user. For example, if there is a car in the road, the device can recognize the machine and relay that to the user. It will also use the smartphone’s camera to observe the environment and the application will perform trigonometric calculations to determine how far away an obstacle is. The application uses screen reader software, such as VoiceOver, to allow for easy navigation of the application. Screen readers are gesture-based and are the way most smartphones are used by blind people. As the user drags their finger across the screen, the phone reads aloud what they are touching. Then, if the user presses again, the phone opens the application as it would normally. This is intuitive for the user as they will have experience with it if they already own a smartphone. The phone application also has an emergency mode that activates when the user is hurt or has fallen by calling 911. Since we can assume the user owns a smartphone and all smartphones have a camera, this is an inexpensive device concept. Additionally, all of the programming is done inside of the application which eliminates the need for external processors. Using a smartphone is also inconspicuous because everyone walks around with headphones and a phone nowadays. The smartphone electric cane ranked well in the cost, ergonomics, and requirements evaluation in our evaluation matrix (see Appendix A). However, it was decided in the evaluation matrix that the phone application has a lot of potential for human error and is not as safe as the other viable design concepts. Similarly, a phone camera is not as reliable as a more expensive external camera. This was also reflected in the evaluation matrix (see Appendix A). These rankings were then taken into consideration when creating a final design. The idea of using a phone application as a processor as well as all of the features built in to the application were carried over to the final design. The smartphone camera, however, left a lot of room for human error. Since the user is blind, they have trouble making sure the camera is pointing exactly where it needs to be.



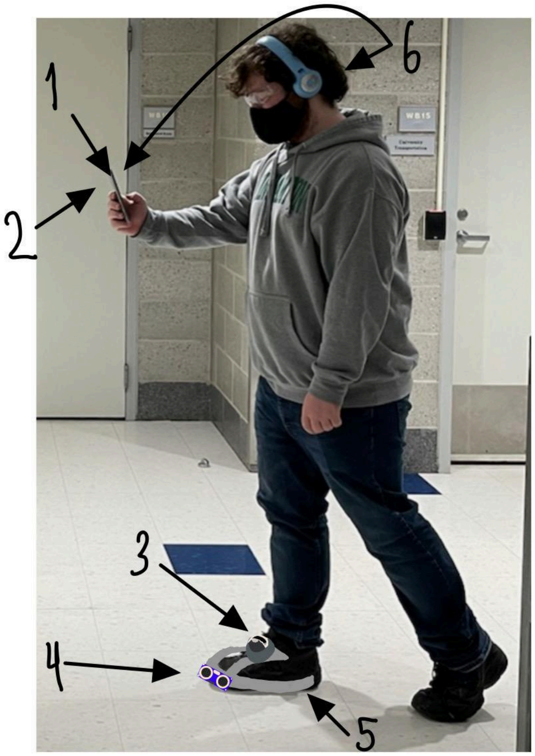


Each viable concept should be their own heading

Final Design Concept - Jake, Evan

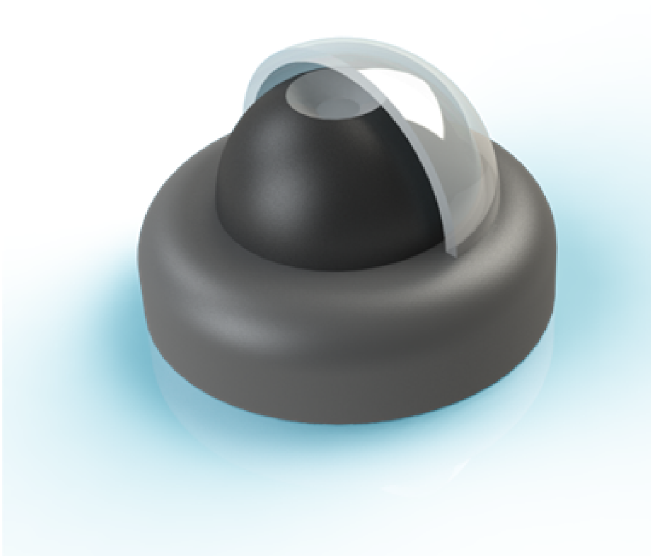
Briefly describe components - Jake

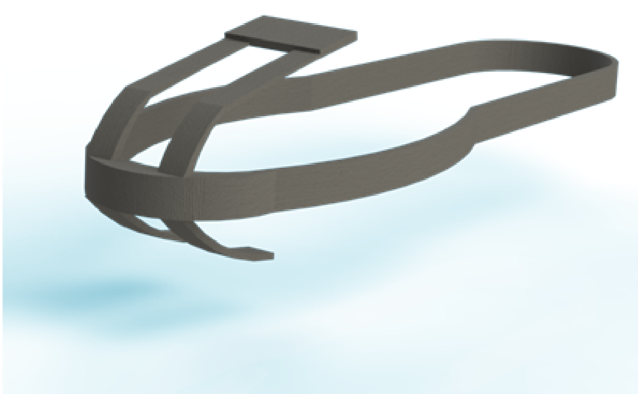
Our device consists of six main design components that work in conjunction with one another through bluetooth. These components are the camera, clip, sensor, phone application, machine learning, and audio/vibration cues. The user places the clip component on one of their feet. The clip is designed to securely fasten the device to the user's body. Attached to the clip is a camera and a sensor. Both of these serve as information gathering components. The camera uses gyroscopic technology to view a wider radius than the sensor while the sensor determines more accurate distances of objects in front of the user. The use of a camera and sensor ensure that the device does miss any possible hazards in front of the user. All of the information gathered from the camera and sensor is processed through a smartphone application. The application also consists of other useful features such as a tutorial and GPS. Then, the device informs the user of any hazards picked up by the camera or sensor through the utilization of audio and vibration. One of the benefits of using a camera to view the user's path is that machine learning can be implemented. This component is able to recognize everyday objects the user interacts or comes in contact with and then communicate it to the user.



1. Phone Application
2. Machine Learning
3. Camera
4. Sensor
5. Clip
6. Audio/vibration cues

CAD Model - Evan





Schematic - Zack

Main Design Components

Camera - Evan (Safety/Cost)

The camera is one of the most important components of the Sensory Substitution Device (SSD). The design is inspired by the wide angle lense security cameras you can find within many stores and schools. This way, the camera is able to see the user's surroundings in a 360 degree range, allowing for increased surveillance to ensure the user is safe at all times. The camera model is shown in figure 6, This addresses the safety evaluation criterion, which was deemed the most important of our evaluation criterion (see Appendix A). To fulfill this criterion, the camera will be positioned on top of the foot, thus allowing it to see around the user at ground level. However, the camera has been modified to compensate for the motion of the user walking, as this may hinder the view of the camera. Using gyroscope technology, the camera remains at an angle from which it can survey the ground in front of the user, while still allowing for the lens to collect data from the rest of the surrounding area. This functionality will be controlled by the application associated with the device, which will be discussed in the ‘Phone Application’ Main Design Component. The camera will be able to read signs surrounding the user in addition to its primary function to sense the changing topography of the landscape, and will output signals to be processed into audio cues. This technology has been implemented in another device that was used to read text documents to visually impaired individuals (Karmel et. al, p. 261). On average, these camera lenses cost around seventy dollars per unit, and while this may be expensive, it still fulfills the cost evaluation criterion, deemed as the least important of our evaluation criteria shown in Appendix A. When designing the camera, the main focus was on fulfilling all of the system level requirements, as seen in Appendix D. The camera is small scale, outputs topography information to the phone application, and upon observation, is far less cumbersome and conspicuous than the current solution to the issue, the white cane.

Clip - Zack (Style/Ergonomics)

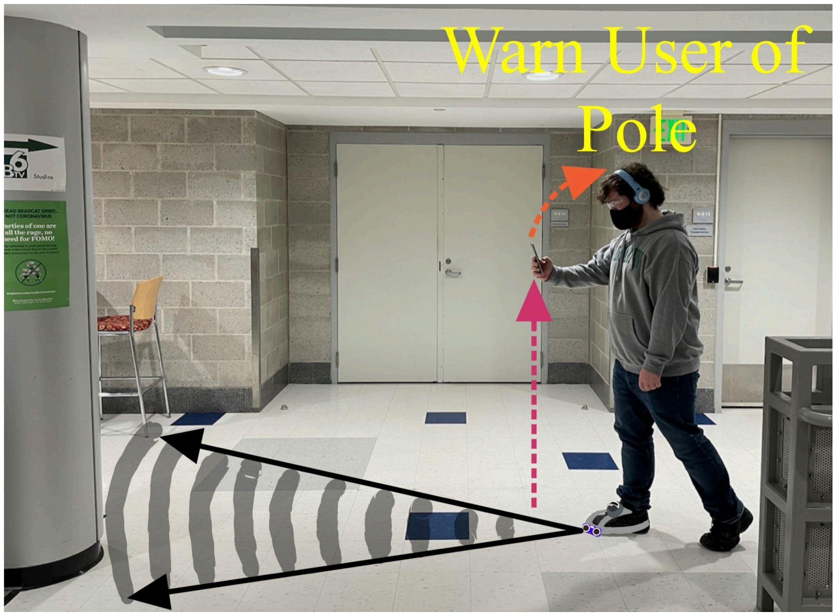
The clip, although sounding like a relatively unimportant component, is actually a crucial part of the Sensory Substitution Device (SSD) design. In order for the camera and ultrasonic sensor to gather data on the ground surrounding the user, a sturdy clip must be prepared to secure the components to the shoe of the blind individual. Rather than appearing as a normal clip, the camera and sensor will be connected to a strap that wraps itself around the user’s shoe. This strap holds the camera on top, and stores the ultrasonic sensor beside the shoe. It is made of a sturdy yet elastic material, such as that which may be found on a backpack strap. The lightweight, subtle design of the clip will keep it inconspicuous and comfortable for the user, making this component fulfill the style and ergonomics evaluation criteria. Style, as a criteria, primarily pertains to how inconspicuous the device appears on the user. Relative to a large, hand-held white cane, the small camera and sensor that is attached to a thin clip on an individual’s shoe is far more inconspicuous. With regard to ergonomics, the clip’s minimal weight and size keeps the user comfortable when wearing the barely noticeable device. These criteria are closely related to the system level requirement AAA 1.2. This requirement states that the device shall be inconspicuous to those around the user, which is fulfilled alongside the style evaluation criteria.

Machine Learning - Matthew (Reliability/Cost)

Machine learning is the development of artificial intelligence without explicit instructions. It can be used to analyze the environment and recognize different objects, such as cars and buses, and can also be used to understand text. In the case of the device, machine learning can be used to notify the user of *what* they are being told to avoid, rather than just telling the user there is an ambiguous object to avoid. Machine learning will reduce the cost of maintenance of the device. Machine learning uses less man-made code because it is developed by an AI through exposure. Machine learning is also open-source, so any man-made changes that are made can be released by other people outside of the team developing the application. Machine learning also allows the device to be more reliable because it will develop with use, and it can memorize routes the user takes routinely to further understand the environment.

Phone Application - Jake (Requirements/Cost)

The communication between all of the device's components is vital to its functionality. Our device utilizes the user's smartphone as the link between the different parts of the device. Specifically, the information gathered from both the camera and the sensor is sent through bluetooth to a specially designed phone application whose goal is to then relay it to the user. Thus, the phone application is the processor of our device. Because we can assume the user already owns a smartphone, using a phone application as the processor addresses the cost evaluation criteria (See Appendix B). When a customer purchases the device, it comes with a single use access code that unlocks the phone application. In other words, the user will never have to pay for the phone application again after first purchasing the device. Because of this, the cost of using a phone application is significantly less than an individual processor pack the user would have to purchase as an alternative. The app also ensures that the device is being used correctly and effectively. For example, whenever the user wishes to activate the camera and sensor, they use the phone app to start it up. Then, after they have turned on the device, the app will also ask the user which foot they will be wearing it on. This user inputted information is important because their other leg may be in view of the camera when they are walking. By putting which foot the device is being worn on, it makes sure that this is not included in the warnings given to the user. The app also accounts for the fact that the user can not visualize what direction the camera is pointing. The camera's gyroscopic movements are controlled through the application's programming. If the camera or sensor is positioned wrong in any way, the phone app processes that and informs the user how to fix the positioning. The tutorial for the device also is included in the phone app to ensure that the user knows how to use it before implementing it into their everyday lives. There are also additional features that add the user's experience embedded in the phone application. The app features voice-over technology, similar to what is used in most smartphones, that the user already is comfortable with. This screen reading software satisfies the style evaluation criteria because this portion of the device should be intuitive for the user if they already own a smartphone. The utilization of a phone application allows the implementation of GPS so that the user can find where they need to go independently without help from others. This allows the user to ensure they are taking routes they are comfortable with. Both the GPS and Screen Reading features help ensure the device satisfies the safety and requirements evaluation criteria. Overall, the phone app mostly satisfies the requirements evaluation criteria because most of the guidelines for our device can be fulfilled by the application. For example, since most people carry smartphones, the features that are within the phone are inconspicuous (See Appendix D).



Audio/Vibrations - Mary (Ergonomics/Style)

Since blind people are missing one of the most important senses, the device is meant to communicate their surroundings to them through the other senses. The device uses audible cues conveyed to the user through bone conducting headphones as well as vibrational cues conveyed through the phone app (refer to figure 5). The reason we are including both forms is to ensure that the user doesn't miss a cue, which could be very dangerous in some circumstances. Using both types of cues also takes advantage of the remaining senses available to a blind person. There will be different kinds of cues indicating the various surrounding objects of which the user needs to be notified. For example, a certain vibration pattern will pair with the audible warning for an upcoming curb. The audible cues consist of clear and concise language to simplify matters for the user. It also is able to read information on signs around the user aloud through the headphones after they are recognized by the camera and translated in the app.

Ultrasonic Sensor - Kali (Reliability / Cost)

The ultrasonic sensor functions in parallel with the camera. Both are located on the clip which is equipped with a wireless output so the ultrasonic sensor can have power without a wire running through the shoe, see Appendix C. The sensor is able to detect objects in its path by sending out waves through the transmitter, and receiving the echo wave through the receiver (Fierceelectronics). The time it takes for the waves to come back is calculated through the sensor to determine how far away an object is from the user. The time varies depending on the velocity of the wave when it is sent out to the surroundings. Therefore, the velocity along with the time it takes for the wave to be sent and received is used in calculating the distance of an obstacle. The velocity of the wave being sent out is constant, so the distance of the obstacle is dependent on the time it takes for the waves to make it back to the sensor. The sensor then sends the distance to the app to inform the user of how far away the object is and that the blind individual should be alerted. The ultrasonic sensor satisfies the evaluation criteria of reliability and safety. The reliability aspect is making the ultrasonic sensor work at the same time as the camera so there is more technology looking for obstacles. Also, if the camera is damaged the ultrasonic sensor will still work and make sure there is a fail safe so the user is not left stranded. The safety aspect is covered because once the connections are done correctly to the power source the ultrasonic sensor will not disconnect unless pulled out. The location of the sensor is located where only the user can pull the sensor out of the power source, so it is a strong safety source. Hence, the ultrasonic sensor demonstrates reliability and safety for the user.

Final Design Assessment - Matthew, Jake

Clear and Concise Verification - Matthew

The device meets the system level requirements AAA 1.0, AAA 1.1, AAA 1.2 and AAA 1.3. The device uses cameras and sensors to warn the user of trip hazards and ground conditions, verifying AAA 1.0. The device provides more information to the user than the white cane through cameras and sensors, as well as machine learning and text to speech technology, which verifies AAA 1.1. The device is more inconspicuous and less cumbersome than the white cane, as the device is smaller, lighter, and hands-free, verifying AAA 1.2 and AAA 1.3. The device is positioned on the foot, which further allows it to be more inconspicuous and less cumbersome than the white cane. Refer to Appendix D for more detailed verifications.

Final Recommendation - Jake

The device provides an effective solution to help the blind in their everyday lives. Since the user places the device on the shoe of the user, it is inconspicuous. The use of a smartphone and headphones is also inconspicuous because everyone walks around with headphones and phones nowadays. This ensures that both the privacy and independence of the user are kept intact. Also, it has a further range than the 36 inches from the white cane. By using bone-conducting headphones and vibration, the device does not impede on remaining eyesight or other senses. The utilization of both a camera and an ultrasonic sensor makes it more accurate than the white cane which is less intuitive and more prone to human error. The phone application is cheaper than any alternate processors and is included in the overall price of the device. Also, the camera and sensor serve as a failsafe to one another in case the other becomes suddenly damaged or ruined. The built-in tutorial ensures the user is fully trained and informed about the device's features before they implement it in their everyday lives. GPS technology saves routes the user is comfortable with and prevents the user from getting lost. The device also provides information about the environment that paints a picture of what is going on around the user. Text-to-speech software recognizes signs and other words around the user and reads them aloud to them. Similarly, machine learning recognizes everyday objects such as cars, busses, etc. and informs the user of what is in front of them. This is very close to what sighted people experience and is far more informative than the white cane. Accidents caused by human error while using the white cane would also be eliminated.

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Appendices

Appendix A: Evaluation Matrix - Zack

		Viable Design 1		Viable Design 2		Viable Design 3	
Criteria	Weighting Factor	Numerical Value	Weighted Value	Numerical Value	Weighted Value	Numerical Value	Weighted Value
Criterion 1: Safety	0.25	2.00	0.50	2.00	0.50	2.00	0.50
Criterion 2: Reliability	0.2	2.50	0.50	2.00	0.40	1.50	0.30
Criterion 3: Ergonomics	0.2	3.00	0.60	2.00	0.40	2.75	0.55
Criterion 4: Style	0.15	1.50	0.23	3.00	0.45	2.25	0.34
Criterion 5: Cost	0.1	2.25	0.23	1.75	0.18	2.50	0.25
Criterion 6: Requirements	0.1	2.50	0.25	3.00	0.30	3.00	0.30
Total 1.0			2.30		2.23		2.24

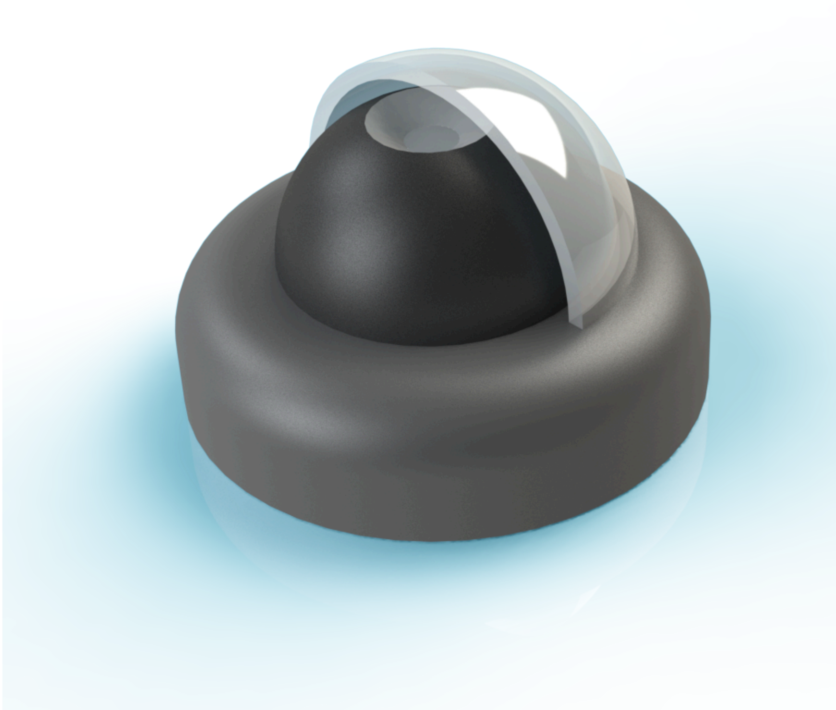
Appendix B: Requirements - Matthew

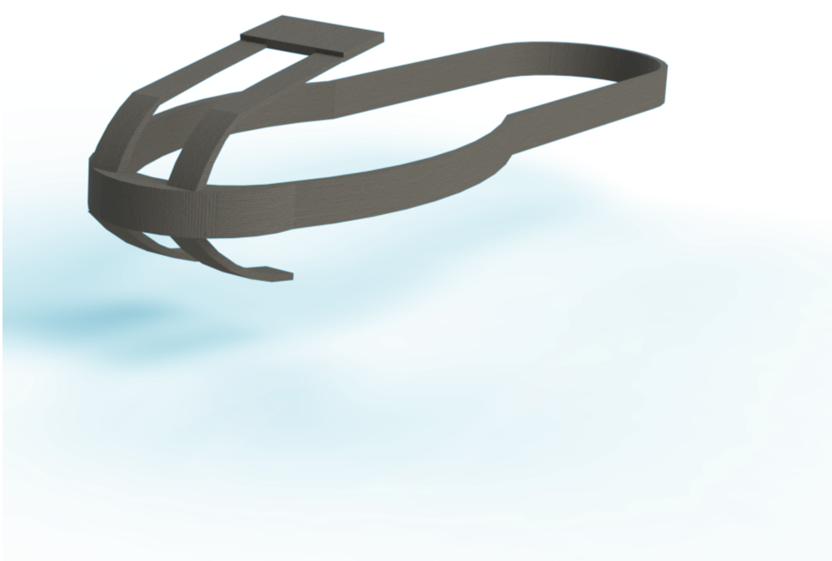
System-Level Requirements:

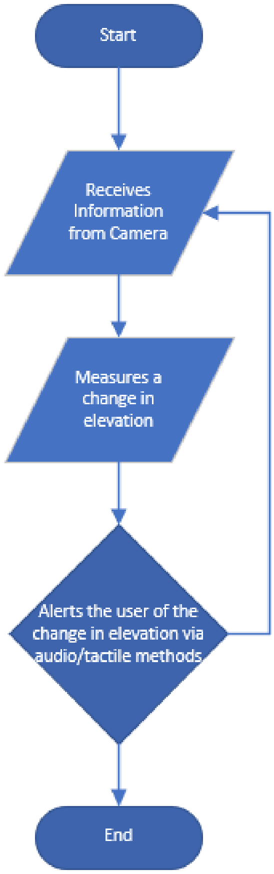
[AAA 1.0] The device shall warn the user of trip hazards and ground conditions.
[AAA 1.1] The device shall provide a way for the user to identify their surroundings to relay more information than a white cane can.
[AAA 1.2] The device shall be inconspicuous to those around the user.
[AAA 1.3] The device shall be less cumbersome than a white cane.

Subsystem Requirements:
[STR 2.1] The device shall be portable. {AAA 1.3}
The device must be able to be transported with the user so that it is always accessible.
[STR 2.2] The device shall not exceed a weight of three pounds. {AAA 1.3}
The device must be worn on the body, and thus it can not be too heavy. Three pounds is a little over the weight of a standard Virtual Reality headset. This provides a weight limit for device design to ensure user comfort.
[STR 2.3] The device shall not cover any remaining eye sight the user may have. {AAA 1.3}
The device must not cover any eye sight or peripheral vision. Even if the user is legally blind, they may still have slight vision left.
[STR 2.4] The device shall not mimic the appearance of the white cane. {AAA 1.2}
The device will need to be more inconspicuous than the white cane.
[FUN 2.1] The device shall be responsive, providing information within a short time, on the order of one second (Elmannai & Elleithy, 2017, p.3). {AAA 1.1}
The device must provide enough time for the user to react accordingly, and thus must relay information quickly.
[FUN 2.2] The device shall have a minimum range of 1.2 meters. {AAA 1.0}
The device must be able to detect the environment surrounding the user more than 1.2 meters away, which is the range provided by the common white cane (Pyun, 2013, para. 1).
[FUN 2.3] The device shall detect hazards on the ground. {AAA 1.0}
The device is expected to find obstacles correctly while informing the user of the obstacles at hand.
[FUN 2.4] The device shall notify the user of hazards detected by the device. {AAA 1.0}
The device must be able to inform the user of hazards once they are detected.
[FUN 2.5] The device shall relay information to the user. {AAA 1.1}
The device must employ features to gather information about the area around the user and transmit this information to the user.
[UI 2.1] The device shall require no more than a week's training. {AAA 1.3}
The device must be intuitive for new users so that it can be implemented into their lives quickly. The white cane usually will take 120 hours of use for a user to train with it. This is about ten days of use. Since this device is intended to be easier to use, it should require less training to understand.
[UI 2.2] The device shall create a heightened level of spatial awareness. {AAA 1.1}
The user must be able to hear natural audio queues while also gaining heightened awareness of their surroundings.
[UI 2.3] The device shall not impede the user's hearing (Hersh, 2008, p. 221). {AAA 1.1}
The device should allow the user to hear their surroundings while operating the device.
[UI 2.4] The device shall enable a blind user to navigate the system on their own. {AAA 1.1}
The user must be able to use the device on their own without external assistance.

Appendix C: Implementation - Evan, Jake







Appendix D: Verification of Requirements - Everyone

Evan – AAA 1.2, and STR 2.4

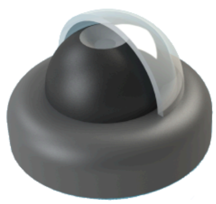
Requirement:

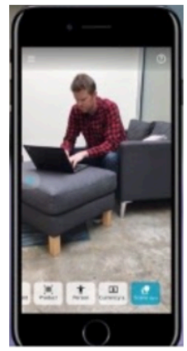
[AAA 1.0] The device shall warn the user of trip hazards and ground conditions.

Verification:

Using the camera and ultrasonic sensor, the device will detect changes in topography, and relay the information to the user via bone conducting headphones after being processed. The functional schematic shown below in the figure illustrates the flow of information through the device.

Figure 1: Functional Schematic





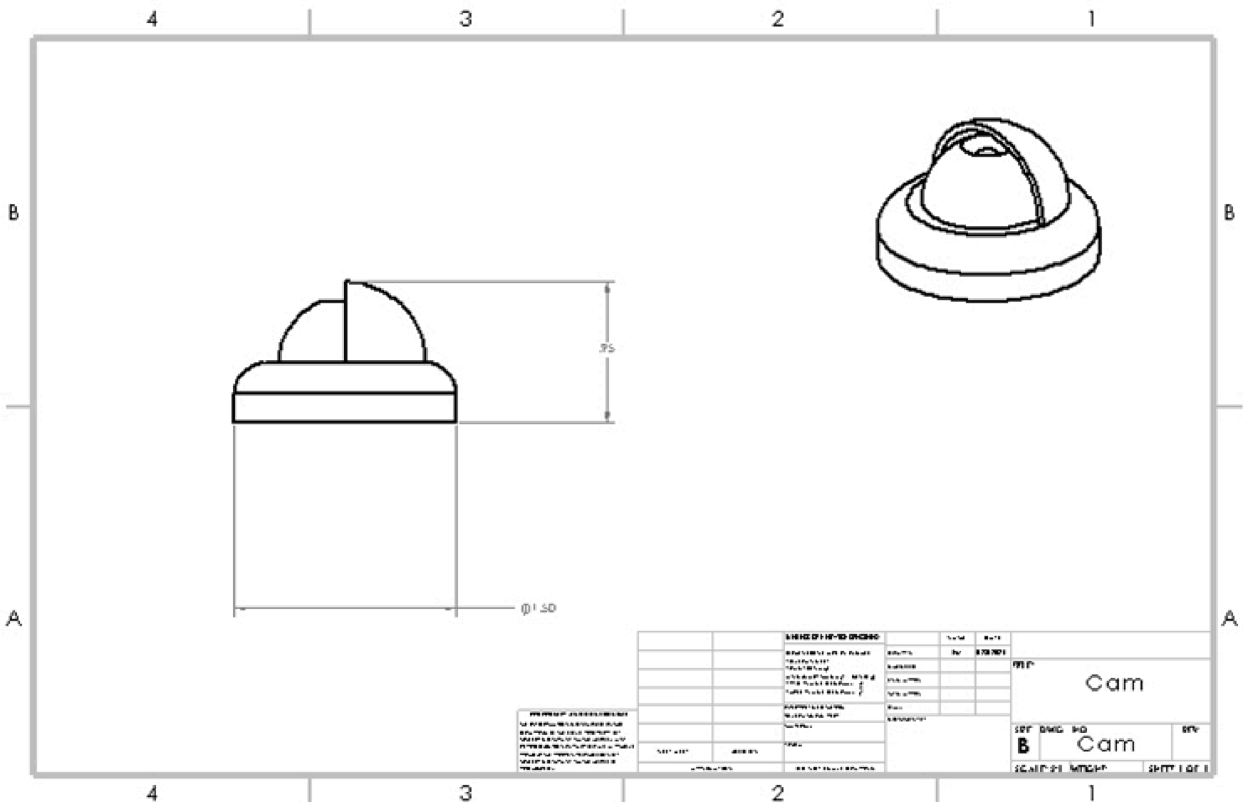
Requirement:

[AAA 1.2] The device shall be inconspicuous to those around the user.

Verification:

In viewing the scale of the camera, as shown below in the CAD drawing in figure 3, the camera itself is only 1.5 inches in diameter, and has a height of .95 inches. When the device is positioned on the user's foot, it will be difficult to view by an individual unless they are looking directly at it.

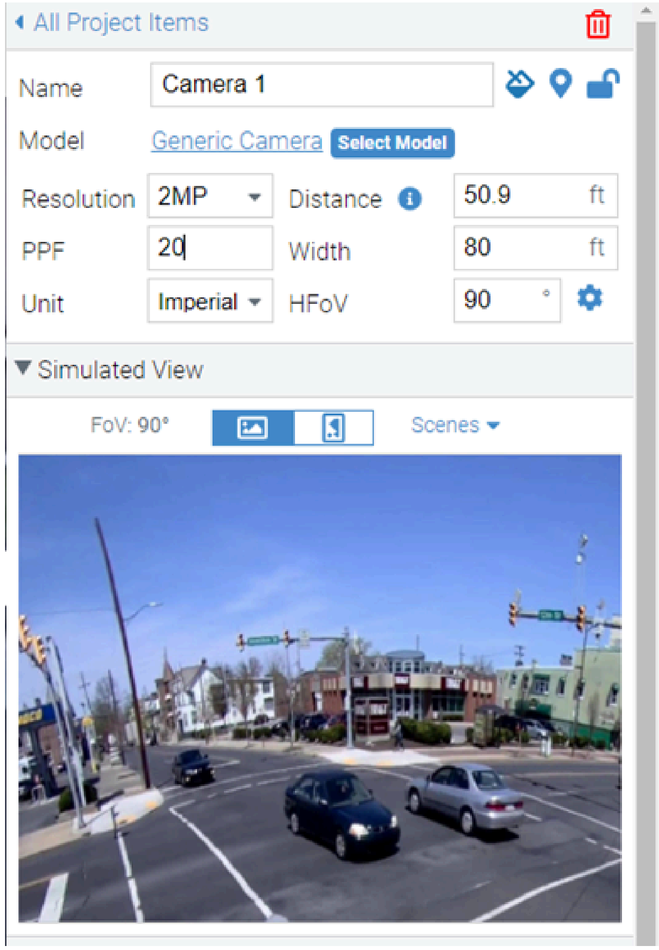
Figure 3: CAD drawing of camera



Matt – FUN 2.2, FUN 2.3, and FUN 2.4

Requirement – [FUN 2.2] The device shall have a minimum range of 1.2 meters.

Verification –The camera the design is based on has a 2-million-pixel resolution. The lowest PPF (Pixels per foot) that an object can be detected is 20 PPF. Using a tool to calculate the PPF of a camera and the specifications of the camera, the farthest distance the camera can see is 50.9 feet, or 15.5 meters. The figure below shows the calculated distance that the camera can see at 20 PPF.



Requirement – [FUN 2.3] The device shall detect hazards on the ground.

Verification – Having the camera and sensor located on the foot allows it to be closer to the ground. The camera and sensor will observe and calculate the distance that objects are from the device and notify the user of close objects.

Requirement – [FUN 2.4] The device shall notify the user of hazards detected by the device.

Verification – The application, camera and sensor will work in conjunction with bone-conducting headphones and will auditorily notify the user if an object appears in front of the user. If there is an object in the path of the user, the user will be notified and can proceed accordingly.

Kali – AAA 1.1, FUN 2.1, and FUN 2.5

Requirement: [AAA 1.1] The device shall relay more information than a **white cane** can by providing a way for the user to identify their surroundings.

Verification: The main components of the camera, clip, ultrasonic sensor, and application allows for the user to obtain more information than they would have with the white cane. The camera sees the surroundings and sends information to the app as to what is actually in the surroundings while the ultrasonic sensor can perceive how far objects are away without having to swing a stick, so objects can not be missed because the stick was not swung in that direction.

Requirement: [FUN 2.1] be responsive, providing information within a short time, on the order of one second (Elmannai & Elleithy, 2017, p.3). {AAA 1.1}

Verification: The device relays information through bluetooth to the user so the information travels instantly. The application on the phone allows for the user to receive the bluetooth information quickly, so as long as the user's phone is on the information will be received quickly. Bluetooth has a transfer speed of 160KB/s (Huawei) so the information can be presented to the user within 1 second.

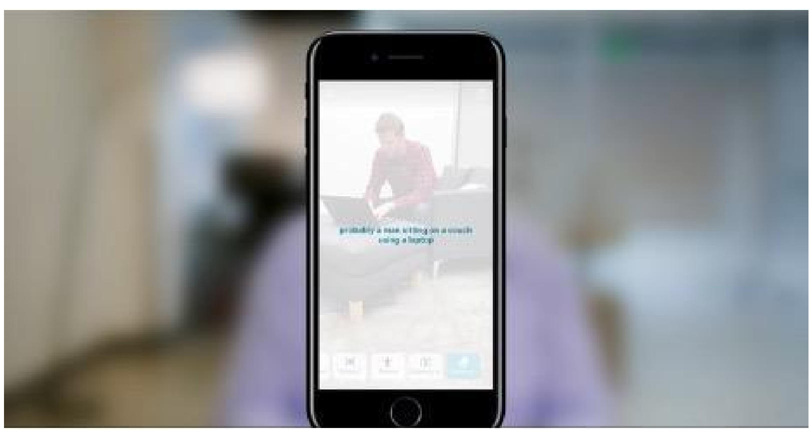
Requirement: [FUN 2.5] The device shall relay information to the user. {AAA 1.1}

Verification: The device relays information to the user by utilizing the phone app. The detection is found through the ultrasonic sensor and camera down on the clip and then sends the information via bluetooth to the user which is given in a language they can understand. By having the connection through the phone the user can easily access and understand the information given and it is on a device they already know how to use.

Jake – UI 2.2, UI 2.3, and UI 2.4

Requirement: [UI 2.2] The device shall create a heightened level of spatial awareness**.** {AAA 1.1}

Verification: The machine learning and text to speech features of the device provide more spatial awareness than the white cane. As seen in Figure 1, machine learning is able to recognize cars, busses, signs, and other objects that the user may come in contact with in their daily lives. After identifying what the user is interacting with, machine learning is able to relay the information to the user.

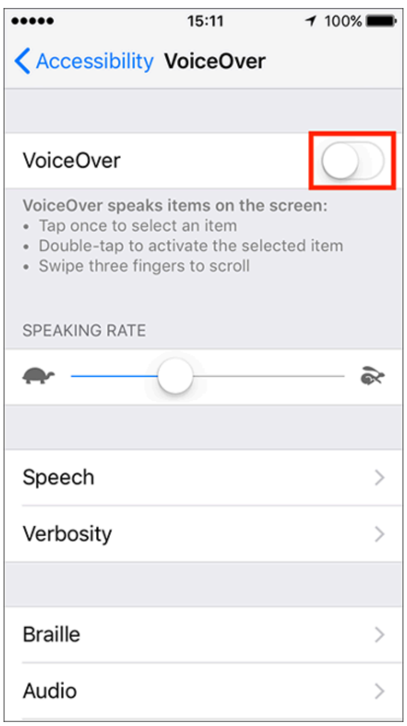


Requirement: [UI 2.3] The device shall not impede the user’s hearing (Hersh, 2008, p. 221). {AAA 1.1}

Verification: The device uses bone-conducting headphones for all audio features. As seen in Figure 2, bone conduction headphones are placed around the ear as opposed to inside of it. Due to this, it will allow the user to fully hear their surroundings while also taking full advantage of the device’s audio capabilities.

Requirement: [UI 2.4] The device shall enable a blind user to navigate the system on their own. {AAA 1.1}

Verification: The app uses Screen Reading technology that is already equipped in most smartphones. As seen in Figure 3, this feature audibly reads whatever the user selects by tapping once on the screen. The device also includes a tutorial that ensures the user knows how to use the device before they begin using it in their daily lives.



Zack – AAA 1.3 and UI 2.1

Requirement:

[AAA 1.3] The device shall be less cumbersome than a white cane.

Verification:

Figure 1 shows a standard white cane. The object, which weighs approximately 200 grams and is, on average, 36 inches long, must be carried by hand and swung from side to side constantly. The new device however, as shown in Figures 2 and 3, is designed to be barely even felt by the user. The attachments will function without needing attention from the user. Unlike the white cane, the new device will not be held, nor will it even need to interrupt the usage of a person's hands at all. The tiny 19 gram camera, being just 0.9 cubic inches, will not be felt by the user in any significant way. These values were gathered from SolidWorks analysis on a generated prototype, and can be found in Figure 4. The clip will attach to the user's shoe, and therefore does not have a fixed size and weight. In SolidWorks, a prototype was made for a men's size 13 shoe, as this is among the largest of shoes available. On this model, as shown in Figure 5, the mass of the clip was still less than that of a standard white cane. Taking the sum of weights and sizes and considering the difference in needed user input, the device design is apparently less cumbersome than a white cane in every way.

Figure 1: A standard white cane

Figure 2: SolidWorks render of the camera design.

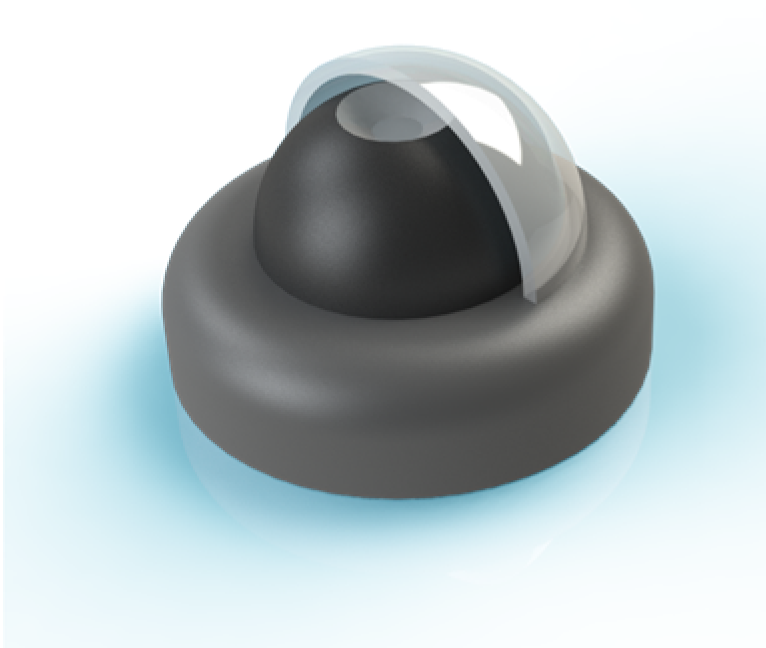


Figure 3: SolidWorks render of the clip design.

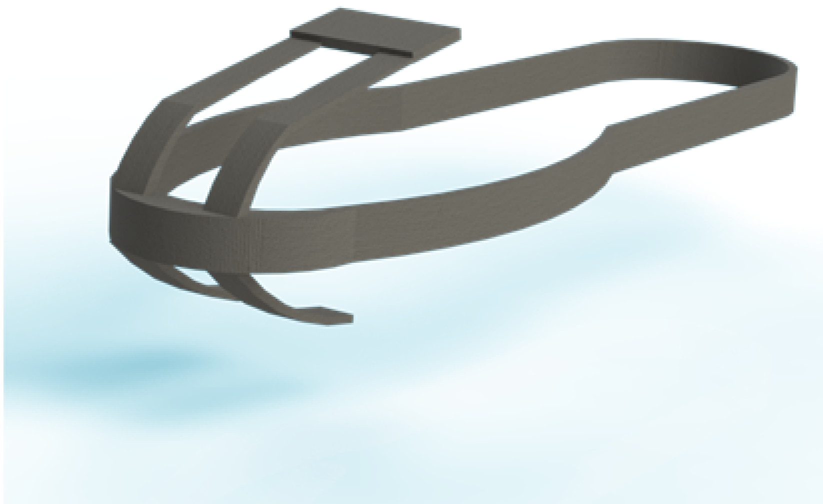


Figure 4: SolidWorks analysis from entered design for the camera.

Mass properties of Cam
Configuration: Default
Coordinate system: -- default --

Density = 16.39 grams per cubic inch

Mass = 14.71 grams

Volume = 0.90 cubic inches

Surface area = 7.38 square inches

Center of mass: (inches)
X = 0.01
Y = 0.29
Z = 0.00

Principal axes of inertia and principal moments of inertia: (grams * square inches)
Taken at the center of mass.
Ix = (1.00, 0.06, 0.00)   Px = 2.28
Iy = (0.00, 0.00, -1.00)   Py = 2.28
Iz = (-0.06, 1.00, 0.00)   Pz = 3.33

Moments of inertia: (grams * square inches)
Taken at the center of mass and aligned with the output coordinate system.
Lxx = 2.28Lxy = 0.06Lxz = 0.00
Lyx = 0.06 Lyy = 3.33 Lyz = 0.00
Lzx = 0.00Lzy = 0.00Lzz = 2.28

Moments of inertia: (grams * square inches)
Taken at the output coordinate system.
Ixx = 3.53 Ixy = 0.12 Ixz = 0.00
Iyx = 0.12 Iyy = 3.33 Iyz = 0.00
Izx = 0.00 Izy = 0.00 Izz = 3.53

Figure 5: SolidWorks analysis from entered design for the clip.

Mass properties of Clip
Configuration: Default
Coordinate system: -- default --

* Includes the mass properties of one or more hidden components/bodies.

Density = 16.39 grams per cubic inch

Mass = 166.10 grams

Volume = 10.14 cubic inches

Surface area = 246.23 square inches

Center of mass: (inches)
X = 0.15
Y = 0.91
Z = 1.05

Principal axes of inertia and principal moments of inertia: (grams * square inches)
Taken at the center of mass.

Ix = (0.00, -0.04, 1.00)	Px = 326.00
Iy = (0.92, 0.40, 0.02)	Py = 1945.17
Iz = (-0.40, 0.92, 0.04)	Pz = 1958.03

Moments of inertia: (grams * square inches)
Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1947.18	Lxy = 4.81	Lxz = -2.97
Lyx = 4.81	Lyy = 1953.02	Lyz = -69.74
Lzx = -2.97	Lzy = -69.74	Lzz = 328.99

Moments of inertia: (grams * square inches)
Taken at the output coordinate system.

Ixx = 2267.70	Ixy = 26.84	Ixz = 22.68
Iyx = 26.84	Iyy = 2140.98	Iyz = 88.69
Izx = 22.68	Izy = 88.69	Izz = 468.68

Requirement [UI2.1]

The device shall require no more than a week’s training.

Verification:

A series of audio & corresponding vibratory queues will be used to transmit information to the user. Audio queues are simple verbal instructions that are easy to comprehend. The vibratory queues will be all that is needed for the user to learn for using the device. Additionally, the phone application will aid in the usage of the device, giving them reminders and more information as desired for when a user does not know the meaning behind a given queue. To learn these queues, which is all that is needed for using the device, will be quick and easy, requiring less than a week of studying to understand. However, using the device in a way where you are primarily dependent on the auditory data transfer will require no additional training.

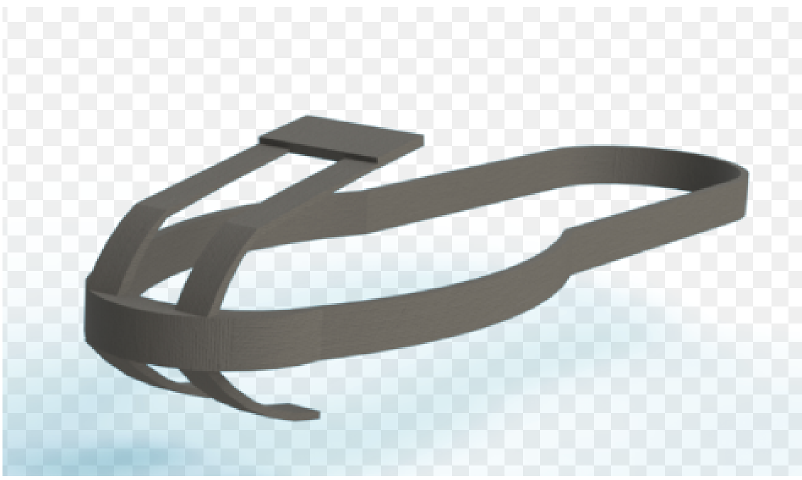
Mary – STR 2.1, STR 2.2, and STR 2.3

Requirement:

[STR 2.1] The device shall be portable. {AAA 1.3}

Verification:

The design of the device consists of three main components: the camera/clip on the foot, the phone app, and the bone conducting headphones. Each of these components is physically independent of the others, therefore making the device portable. This is shown in the pictures of the clip design and example bone conducting headphones shown below.



CAD of the clip that will attach the camera to the shoe

A picture of a pair of Tayogo bone conducting headphones used for reference in the design implementation

Requirement:

[STR 2.2] The device shall not exceed a weight of three pounds. {AAA 1.3}

Verification:

As shown in the photo below, the camera clip and camera weigh 180.81g together, which is about .399lb. The average smartphone also weighs about .5lb. A set of bone conducting headphones weighs around 3.2oz, which is about .2lb. Together, these add up to weighing only about 1.1lb, which is well under three pounds.

Product information

Color:**Grey**

Product Dimensions	6.3 x 5.5 x 2.4 inches
Item Weight	3.2 ounces
Manufacturer	Tayogo
ASIN	B07Y1QMHW5
Item model number	S2-Grey-0918
Batteries	1 Lithium ion batteries required. (included)
Customer Reviews	1,667 ratings 4.0 out of 5 stars
Best Sellers Rank	#501 in Earbud & In-Ear Headphones
Date First Available	September 18, 2019

Product Description of Tayogo bone conduction headphones found on Amazon

Mass properties of Cam
Configuration: Default
Coordinate system: -- default --

Density = 16.39 grams per cubic inch

Mass = 14.71 grams

Volume = 0.90 cubic inches

Surface area = 7.38 square inches

Mass Properties of Cam

Mass properties of Clip
Configuration: Default
Coordinate system: -- default --

* Includes the mass properties of one or more hidden components/bodies.

Density = 16.39 grams per cubic inch

Mass = 166.10 grams

Volume = 10.14 cubic inches

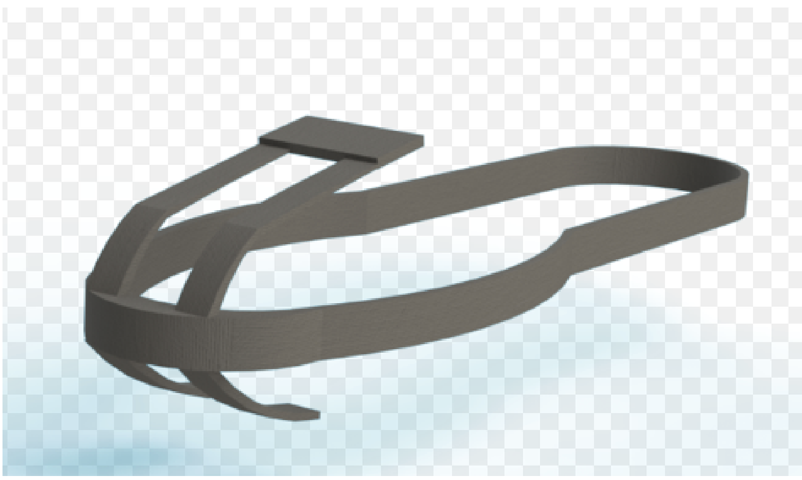
Mass Properties of Clip

Requirement:

[STR 2.3] The device shall not cover any remaining eyesight the user may have. {AAA 1.3}

Verification:

The camera is located on the shoe of the user and the bone conducting headphones are located on the head of the user, both well out of the way of the remaining eyesight of the user, as can be seen in the following figures.



CAD of the clip that will attach the camera to the shoe

A picture of a pair of Tayogo bone conducting headphone to show that they do not interfere with eyesight

Requirement:

[STR 2.4] The device shall not mimic the appearance of the **white cane**. {AAA 1.2}

Verification:

As shown below in figure _, it is clear to see that the device does not resemble the white cane. The device depicted will be no bigger than the user's shoe size, and will be accompanied by a phone application, as well as bone conducting headphones, also shown below.

Appendix E: Gantt Chart

Gantt Chart

Gantt Chart

Gantt Chart