Assistive Walking Shoe for the Blind

Group 39 - Abhishek Bhandari (anb4), Kousthubh Dixit (kmdixit2), Vyom Thakkar (vnt2)
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TA : Jonathon Hoff

1. Introduction

1.1 Objective:

Problem statement:

The project that we decided to modify and work on is the project 'Electronically Enhanced Blind Probing Cane' (Team 18) from Spring 2019. The existing solution is an electronically supplemented traditional walking cane, using LIDAR sensors to detect obstacles and a haptic feedback system using a bracelet peripheral that is used to alert the user when an object is within 1.5 metres from the user. The cane communicates with the user by varying the intensity of vibrations in a bracelet that the user wears as he/she approaches an obstacle. Thus, the scope of the problem that we are trying to solve is: coming up with a solution that improves the walking experience of users with visual impairments, allowing them to better navigate their path around environments that have obstacles. We need to do so by addressing the following challenges: 1) Giving the user a more intelligible form of information about the distance to the detected obstacle rather than just vibrational feedback, which will give the user a much better idea of how far ahead an obstacle is because he can intuitively think of it in terms of how far ahead he needs to walk rather than the degree to which his bracelet has increased in vibrations.
2) The existing project solution will not be able to detect moisture or water and this is definitely a big challenge because if the user steps on water without knowing it and continues to walk on wet surfaces, he/she could seriously injure himself/herself.
3)The existing solution is not equipped to deal with rain and dirt which could cause issues in the practice.
4) The existing solution uses sensors that are bulky and expensive, and it requires the use of a specialized cane that must be carried around.

Proposed solution:
In our new implementation, we aim to fundamentally redesign the cane implementation by coming up with a solution which consists of a mounting structure (analogous to a sandal without its sole that uses velcro-based straps to attach to the user's right shoe.)that can be placed on top of a shoe such that it contains an ultrasonic sensor (Sensor 1) facing forward which informs the user of how many steps away an obstacle is (by converting the raw distance to the obstacle to a personalized step distance metric based on user's height), from the direct line of the user's gait. Our solution will also alert the user if the surface that the user is walking on is wet, with the

help of electrodes that are connected to a fluid detector IC. In the current implementation, the device will only need to be placed on the right shoe and not the left. We use three additional ultrasonic sensors , one (Sensor 2) to provide the signal to the microcontroller when the foot is flat on the ground, two (Sensors 3 and 4) to track the left foot's position so that it isn't detected as as an obstacle by Sensor 1. We will use a plastic encasing on all the sensors and components to ensure that they aren't affected by rain or dirt.

We address all of the challenges mentioned in the problem statement in the following way:
1) The user is given a step-count which will give him/her a much better idea of how far ahead an obstacle is because he can intuitively think of it in terms of how far ahead he needs to walk to encounter the obstacle rather than relying on his ability to interpret changing vibrational sensations.
2) Our device uses a moisture sensor that will alert the user if he/she steps on water and with this new information, the user can slow his gait and be more conscious while walking. This could help prevent a major accident.
3)By encasing all the wires, the top exposed parts of the sensors and the microcontroller in plastic encasings, we ensure that our device can operate in rain and dirt.
4)Our device uses the inexpensive, light, and small ultrasonic sensors which cost a fraction of the amount that lidar sensors cost. Additionally, our device can be used as an attachment to a regular shoe and does not require an entire other device such as a cane to be carried everywhere the user goes.

1.2 Background:

A key point that we hoped that our solution can deliver upon, is improving the nature of feedback that we provide the user vis-a-vis the obstacles. One of the drawbacks of the current implementation is that the cane (and the sensors on the cane, depending on their placement) can sometimes miss obstacles that are relatively small and that are directly in the path of the user. The LIDAR sensors on the cane are limited by the orientation in which the user holds the cane (as well as their relative placement on the cane with regards to a given obstacle), which can lead to certain obstacles going undetected. The paper "*Usability and Design Guidelines of Smart Canes for Users with Visual Impairments*" by Kim et. al [1] mentions that walking canes and smart walking canes are not very effective at finding obstacles below knee-level (floor-level detection) or at distances greater than 1m. These canes normally make an angle of 50^o to 60^o with the ground because of which the sensors on the cane face upwards and are hence not very effective at detecting obstacles below the knee level. Our solution helps to address this problem, since the range of the ultrasonic sensor of our system which is placed in the front of the shoe, is in a line parallel to the line of vision of the user, and thus, would be able to accurately detect obstacles directly in the gait of the user near the floor to knee level.

On a similar note, one very critical obstacle that the existing solution is not able to detect is moisture or the "wetness" of the surface on which the user is walking on. The inability for a visually-unaware user to detect the presence of a liquid on the given surface that they are walking on can have severe repercussions. We wanted to develop a solution that can alert the user if the surface that the user is walking on acts as a slip-hazard. Hence, we decided to augment our solution with fluid detector ICs that can convey information about the wetness of the surface to the user.

Moreover, another specific area that we wanted to improve upon in the current implementation was providing the user with a more tangible feedback about the distance of an obstacle from the user's current path. The haptic feedback system of the current solution underscores the proximity of an obstacle by increasing the intensity of vibration of the haptic sensors, however, determining how "close" an obstacle is, to warrant a specific level of vibration intensity is an attribute that is open to interpretation. This places the burden on the user to interpret a given intensity of vibration, which can lead to confusion and uncertainty. We plan to eliminate this problem in our solution by converting raw data about the distance of the obstacle to a personalized step distance metric based on the user's height. Based on the article "*How to Measure Stride Length*" [2] we found that the step size for females is given by the formula $Height \times 0.413$ and the step size for males is given by $Height \times 0.415$. This would help in giving the user a more definitive estimate of the proximity of different obstacles in their path.

Moreover, with respect to the general design of the current product, we also found areas that we could improve upon. Firstly, LIDAR sensors are bulky and expensive [7] , and are more well suited to applications that require long range sensing and detection. Since, we only care about obstacles close to the user for this specific application, we felt that using LIDAR sensors might be an overkill. We plan to replace these LIDAR sensors with ultrasonic sensors which are cheaper, lighter and are ideal for short range detection. The paper "*Usability and Design Guidelines of Smart Canes for Users with Visual Impairments*" by Kim et. al [1], mentions that based on surveys that were conducted, one of the drawbacks of the smart cane was the price range, and that users who needed one often could not afford one. By replacing LIDAR sensors with ultrasonic sensors and by redesigning the cane and peripheral haptic feedback system with a system designed to fit on the user's shoe, we believe that we can bring down the price of our solution to make it more affordable. Secondly, the current product consists of a walking cane as well as a peripheral bracelet (for haptic feedback). We feel that having too many supporting devices might be an impediment for the user, rendering the product unusable if the user forgets to carry one of the supporting devices. We feel that this problem calls for a solution that can seamlessly integrate with the walking experience of the user, reducing as much unnecessary clutter and confusion as possible. Hence, we decided to build our product onto the shoe of the user in a way such that the user does not need to carry additional equipment, and which we believe is a more hassle-free solution than the existing one.

1.3 High-level requirements:

1) The system must be able to detect obstacles that are upto a range of 1.5 m from the user and must be able to provide accurate audio feedback (about the distance of the obstacle in units of number of steps) to the user when the said obstacle is encountered.
2) The system must be able to detect if the surface that the user is walking on is wet.
3) The product, which is integrated on the user's shoe, must not hinder the capacity of the user to freely walk in any manner.

2. Design

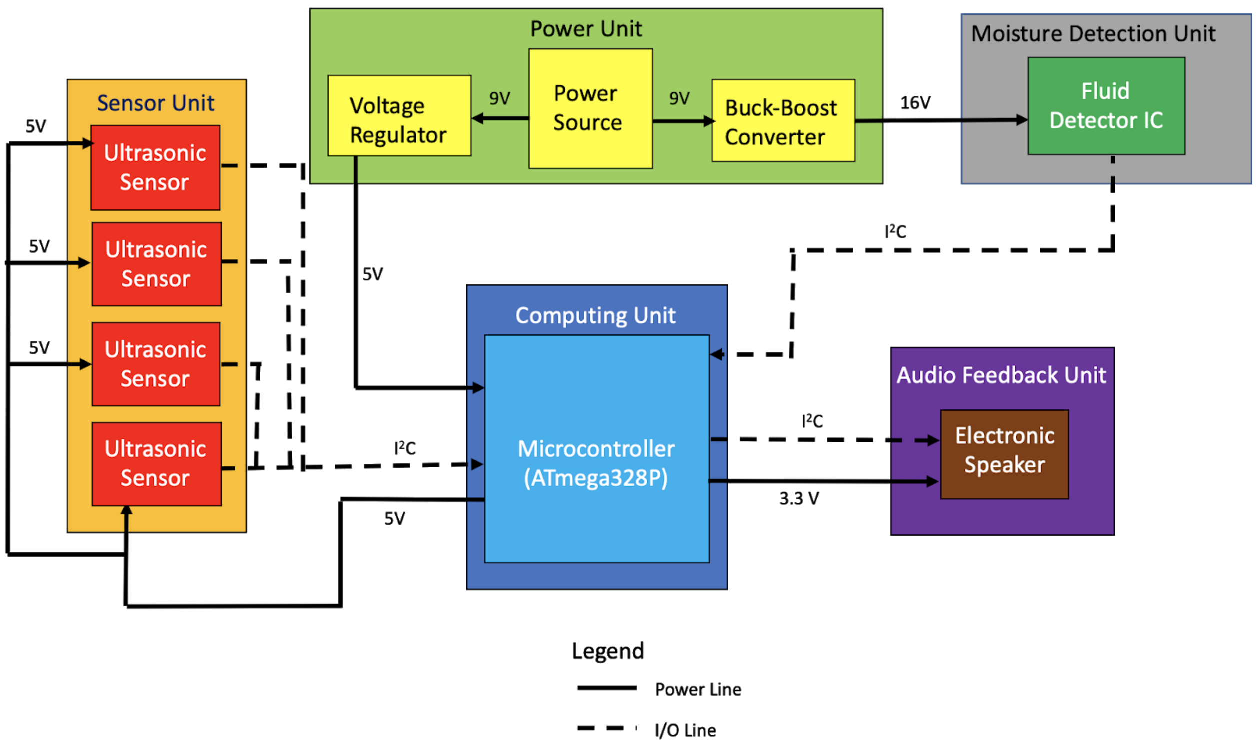

Figure 1. Block Diagram

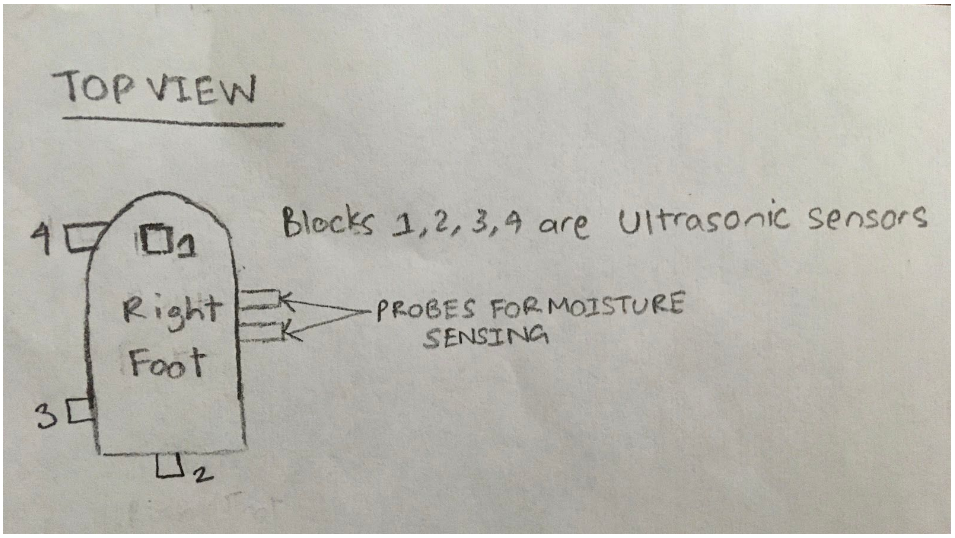

Figure 2. Physical Design

2.1 Power Unit:

The function of the power unit is to provide a stable voltage to all of the electrical components in our system at their specified operating voltage. The voltage regulators will be responsible for stepping down the battery voltage and maintaining it at a stable output voltage of 5V in order to power the microcontroller and the four ultrasonic sensors. A buck boost converter will be used to obtain a stable voltage of 16 V to the moisture detection IC. The microcontroller will draw a current of approximately 300 mA, the sensors will each draw an operating current of 15 mA, the audio unit will draw 3.5 mA and the lithium battery that should be able to provide up to a continuous current of 1000mA.

2.1.1 Power Supply:

We are planning to use a 9V Li-ion battery that will feed into the voltage regulators and then will be used to power the various subsystems.

2.1.2 Voltage Regulator:

The first voltage regulator will be responsible for stepping down the battery voltage to a steady 5V required to power the microcontroller,the ultrasonic sensors. The second regulator will step down the battery voltage to 3.3V to power the audio unit.

2.1.3 Buck-Boost Converter:

We will use this converter to provide a stable voltage of 16V to the moisture detecting IC.

2.2 Computing Unit:

The high-level function of the computing unit is to interpret the data output from the ultrasonic sensors and relay information to the audio unit which will convey the appropriate information to the user.

2.2.1 Microcontroller:

We will use the ATMega328P microcontroller chip for our design. It will interface and communicate with the sensor unit, moisture unit, as well as the audio unit using the GPIO pins on the microcontroller.

2.3 Sensor Unit:

Our sensor unit consists of four ultrasonic sensors. (Sensor 1) One will be placed on the front side of our mounting structure at an angle of 5 degrees with the horizontal (floor) facing down (This angle may need to be tweaked during the physical testing phase). (Our mounting structure consists of a velcro strap-on structure on a shoe (similar to a sandal without a sole) The second sensor(Sensor 2) will be placed at a 90 degree angle facing downwards at a position closer to the back of the foot. The third(Sensor 3) and fourth (Sensor 4) sensor will be placed on the inner side of the right shoe at angles of about 15 degrees and their purpose is to monitor the position of the left foot so that only meaningful readings are recorded by Sensor 1 on the right foot.

2.4 Moisture Unit:

The moisture unit consists of a moisture detecting IC and two probes that will be placed on the side of the right shoe. It will be responsible for detecting any upcoming moist/wet surfaces and relaying that information to the microcontroller in order to alert the user.

2.5 Audio Unit:

The audio unit consists of a speaker that will produce a sound to alert the user of how far the nearest upcoming obstacle is in terms of the number of steps the user must take before stopping to avoid a collision with the obstacle. It will also produce a different sound if the user steps on a moist/wet surface in order to alert the user to be careful.

Table 1. Subsystem Requirements

Subsystem	Requirements
Power Unit	1) Must be able to provide a regulator DC voltage based on the requirements of the sensor unit, computing unit, each of which require 5V with a maximum tolerance of +/-5% in supply voltage. 2) The buck-boost converters must also be capable of providing a constant DC voltage to power the audio unit(12V) and the moisture sensor(16V) with a maximum tolerance of +/-5%.
Computing Unit	1) The computing unit must relay accurate information from sensor unit to audio unit to convey step information to the user with an accuracy of +/-7.2% of the average male stride length. 2) The total time of computation should take no more than 1/100 (because even brisk walkers' soles make complete contact with the ground for about that time so we cover our worst case) of the time taken for the ultrasonic sensors to detect an obstacle.
Sensor Unit	1) The main ultrasonic sensor(labelled 1 in the physical design diagram) must be capable of detecting obstacles of upto 150 cm ahead. 2) The second ultrasonic sensor (labelled 2 in the physical design diagram) must be capable of accurately detecting distance to the ground from a 7cm height (reference height at which sensor is fixed on mounting structure above ground) such that every time the back of the foot takes off from the ground, sensor 1 stops taking readings. 3) Ultrasonic sensor 3 and 4 should be capable of accurately tracking the left foot, such that each sensor's output is used to track the foot in a 15 cm arc in a 30 degree wide angle. Sensor 1 readings should only be used when sensor 3 outputs a low and and sensor 4 outputs a high in the 15 cm arcs each (left leg is behind right leg and so does not impede the "vision of sensor 1" on right foot. 4) The electrodes should be able to detect moisture accurately and to test for this the output will need to be high whenever the shoe steps on wet surfaces.
Moisture unit	1) Must be able to detect a wet surface as soon as the user steps onto the surface.
Audio unit	1) Speaker must be capable of producing audio in the more sensitive parts of the detectable human hearing range of

	sounds of frequency 1 kHz to 4 kHz(preferably at not too high a frequency) so as to convey clear information to the user.

2.5 Risk Analysis:

The biggest limitation of our implementation is that our ultrasonic sensors may not be able to detect surfaces that tend to be relatively acoustically soft because most of the sound won't be reflected off of these surfaces but instead it will be absorbed. If the reflected sound wave is attenuated beyond a point, it will not be detected by the ultrasonic sensor's receivers, and hence the user will not know when he is approaching such surfaces. Typically though, if it isn't intended by design, a user will rarely encounter such surfaces if at all. Just being acoustically soft isn't enough . The surface must be so acoustically soft that it absorbs almost all of the sound. This typically will not happen, but it is a risk that we are aware of.

Since our shoe is a proto-type, we are using a default average height of 69 inches (5 feet 9 inches) to determine our stride length. Users with heights significantly different from this value, may receive slightly erroneous step-counts, as there isn't a way on our device to user-input height as of now. It would have to be changed programmatically on the ATMEGA chip.

Thirdly, over a substantial period of time the moisture probes may get oxidized and if they are not quickly replaced, their sensitivity might be severely impacted, which could result in water not being detected and a user slipping and falling.

Lastly, if a blind person were to wear the shoe with the sensors and run, detecting water as he/she steps into it may be too late to prevent him/her from slipping and early detection would be needed rather than instantaneous detection. While the fourth point isn't a major concern because we do not expect blind users to run while wearing the shoes, it still remains a slight risk, however improbable.

3. Ethics and Safety :

Since we will be using lithium batteries in our project, a safety concern associated with using lithium batteries is called "thermal runaway" which causes the battery to overheat and leads to operational failure. Thermal runaway can also cause the battery to heat up to a point that it can catch a fire, thus we need to be cognizant of the fire hazards that are associated with the use of lithium batteries in our project. In the case of a fire, we will make sure that we follow the protocols and safety measures that were discussed in the safety training online lab module which was introduced at the start of the course.

In our project, we will be using ultrasonic sensors for obstacle detection. We reviewed the safety guidelines and precautions enlisted by Omron Industrial Automation [5]. As stipulated by these guidelines, we will ensure that the product and the associated ultrasonic sensors are not used at an operational temperature of greater than 70^{o} C, which is the upper limit of operational temperature for ultrasonic sensors as mentioned in the article "*Ultrasonic Sensors Knowledge (Part 4): Influences on Measurement Accuracy*" [6]. We will also ensure that we do not use these ultrasonic sensors near any air nozzles (which contain multiple frequency components), that have been found to negatively impact the operation of ultrasonic sensors. In order to protect the ultrasonic sensors from water droplets, we will be using plastic encasing to protect the ultrasonic sensors. Furthermore, we do not plan to use the ultrasonic sensors in low temperatures less than 0^{o} C, because the vinyl cables associated with the ultrasonic sensors are found to bend and break in these conditions.

Moreover, exposing the PCB to water or rain could cause a short-circuit and lead to operational failure, so we will make sure that we do not expose the PCB to water and we thus plan to protect the PCB using a plastic encasing similar to the ultrasonic sensor. In addition, we will also always make certain that we will be using the different electronic components in our system within their operational usage limits including but not limited to voltage, current, temperature and humidity limits.

We have also carefully reviewed the IEEE [3] as well as the ACM Code of Ethics [4] and in the following section of our Project Proposal, we will briefly discuss some of the codes that are relevant to our project and how we plan to go about upholding and abiding by these guidelines to the best of our abilities. Starting with points 1. and 9. of the IEEE Code of Ethics [3] and point 1.2 of the ACM Code of Ethics [4], we will ensure that in designing, implementing, experimentation and testing of our product, we will hold the safety, health and well-being of the general public to the highest order and we will ensure that if and when someone tests or uses our product we will do so only after rigorous and thorough testing, and only if we deem it completely safe to use to the best of our knowledge.

In compliance with point 2. of the IEEE Code of Ethics [3] and point 3. of the ACM Code of Ethics [4], we will ensure that all of the results, estimates and decisions that we present over the course of the development of our project, will be based on data that we collect during the design, implementation and testing phase. All the estimates and results that we present and all the decisions that we make will always be backed by genuine data, that we either obtain from trusted external sources or through the data that we ourselves collect, understand and analyze. We vow to not fabricate results, and we promise to be as open, honest and trustworthy as we possibly can.

We have taken up this project because we are genuinely intrigued by the scope of our project, the impact that technology can have in order to make a difference in people's lives and to build up our technical knowledge and competence. We vow that the actions of our group will always be guided by honest and genuine intentions, and in this spirit, we vow to abide by point 5 of the IEEE Code of Ethics [3] and points 1.5 and 2.2 of the ACM Code of Ethics [4].

Our group is committed to treating all people fairly and we vow to not discriminate based on including but not limited to race, gender, sexual orientation, age, religion, disability and nationality. We will always celebrate diversity and inclusivity in the work that we do and will fully abide by point 8. of the IEEE Code of Ethics [3] and point 1.4 of the ACM Code of Ethics [4].

We will always hold the privacy of our potential users to the highest regard and we will ensure that the project that we build is in no way collecting unauthorized data from the users. In our project we will be collecting information about the user’s height in order to estimate the stride length of the user, but this will be done only on conditional terms if the user wishes to provide this data. We will have a default height parameter that we will manually enter into our product in the case that the user wishes to not provide this data. We also vow that the user will ‘own’ this provided data in all forms and we shall not disclose this information to any third-party sources. We will also completely abide by point 1.6 in the ACM Code of Ethics [4].

Lastly, throughout the semester we will be reviewing previously published literature and will be analyzing their results, observations and conclusions in order to guide our project. We vow to properly credit other people’s work and cite this work in an appropriate format in the reports that we submit. We will hold to highest regard, point 7 of the IEEE Code of Ethics [3] and point 1.5 of the ACM Code of Ethics [4].

References :

[1] S. Y. Kim, “Usability and Design Guidelines of Smart Canes for Users with Visual Impairments,” *International Journal of Design*, 2013.

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[5] “Safety Precautions of Ultrasonic Sensors Cautions for Ultrasonic Sensors: OMRON Industrial Automation,” *OMRON*. [Online]. Available: http://www.ia.omron.com/product/cautions/50/safety_precautions.html. [Accessed: 04-Apr-2020].

[6] Fuchs, “Ultrasonic Sensors Knowledge (Part 4): Influences on Measurement Accuracy,” *Pepperl Fuchs*, 20-Jul-2018. [Online]. Available: https://www.pepperl-fuchs.com/usa/en/25518.htm. [Accessed: 04-Apr-2020].

[7] Shawn and Shawn, “Types of Distance Sensor and how to select one?,” *Seeed Enables Your Hardware Innovation Needs*, 01-Oct-1969. [Online]. Available: https://www.seeedstudio.com/blog/2019/12/23/distance-sensors-types-and-selection-guide/. [Accessed: 04-Apr-2020].