Indoor Navigation for the Blind

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Introduction

Objective:

Blind people face visual challenges throughout their lives. In an interview, the participants noted that the most important problems they faced were unsafe sidewalks, existence of obstacles, navigation in new spaces, people moving things around, and crossing streets. [1] In fact, many cities have adapted tactile paving in public buildings and sidewalks to alert the blind of stairs, roads, and platform edges. [2] [3] However, navigating space and especially in large indoor areas such as airports, malls, and apartment complexes still remains a challenge, and is currently largely done through guide dogs, assistance or the individual having to memorize the layout (usually for their homes and personal spaces). [4] The guide dogs are extremely sensitive to the cues from the blind person and are trained to find exits, stairs and elevators, and even respond to threats. [5] [6] [7] However, wayfinding through airports and large indoor locations without assistance still remains extremely difficult because of the complex indoor layouts, lack of directional-aid in non-visual formats and the loud constant echo-noises which causes disorientation. [1] [8] In fact, independent grocery shopping is still one of the most functionally challenging tasks a blind and visually impaired person can do; therefore, it is essential that we design spaces and build the relevant infrastructure to be more inclusive. [7] The architecture and the lack of accessibility causes the blind person to largely avoid these spaces or only use them when absolutely necessary. [1] [7] [8]

Our goal is to attempt to solve the wayfinding task for the blind and visually impaired individuals in indoor spaces such as apartment complexes, malls etc. The wayfinding task includes locating the person and then subsequently successfully navigating him/her until the person's destination through constant feedback. To build the wayfinder application we will build "walkability" maps of the indoor spaces and set up bluetooth beacons in such a way that their signals cover the entire space. Additionally, the blind person will also be carrying a bluetooth compatible wearable-device, which will connect to the bluetooth beacons. The main idea is to be able to locate the person within the building with an accuracy of 1-2 meters using the bluetooth signals and then guide them to their destination using the pre-built map through haptic and vibrational feedback. Our application will only handle the navigational aspect of this problem.

Background:

There are a couple of companies that solve this wayfinding problem for the blind, for indoor and outdoor settings. BlindSquare is one of the world's most popular companies for outdoor settings, which announces points-of-interest such as street names, and saved locations; it helps users look up information regarding their surroundings with the help of GPS and third-party-apps. [9] IndoorAtlas is an application for indoor positioning system, which finds your position with the help of bluetooth beacons, WiFi signals, and barometric pressure to measure elevation. The application can be downloaded off the Apple or Android Store; however, the application is not for the blind or visually impaired since it is simply indoor positioning technology for retail, healthcare and airports. [10] Regardless, the use of such bluetooth beacons is on the rise because of the large number of bluetooth compatible devices already in production. Indoors is one such company currently operating in the Los Angeles airport, along with a company called Wayfindr, which is operating in the London Tube. Indoors has a similar structure in place where they first create high quality maps of the system and then use iBeacons with some more input from WiFi to get the location and provide directions. [11] [12]

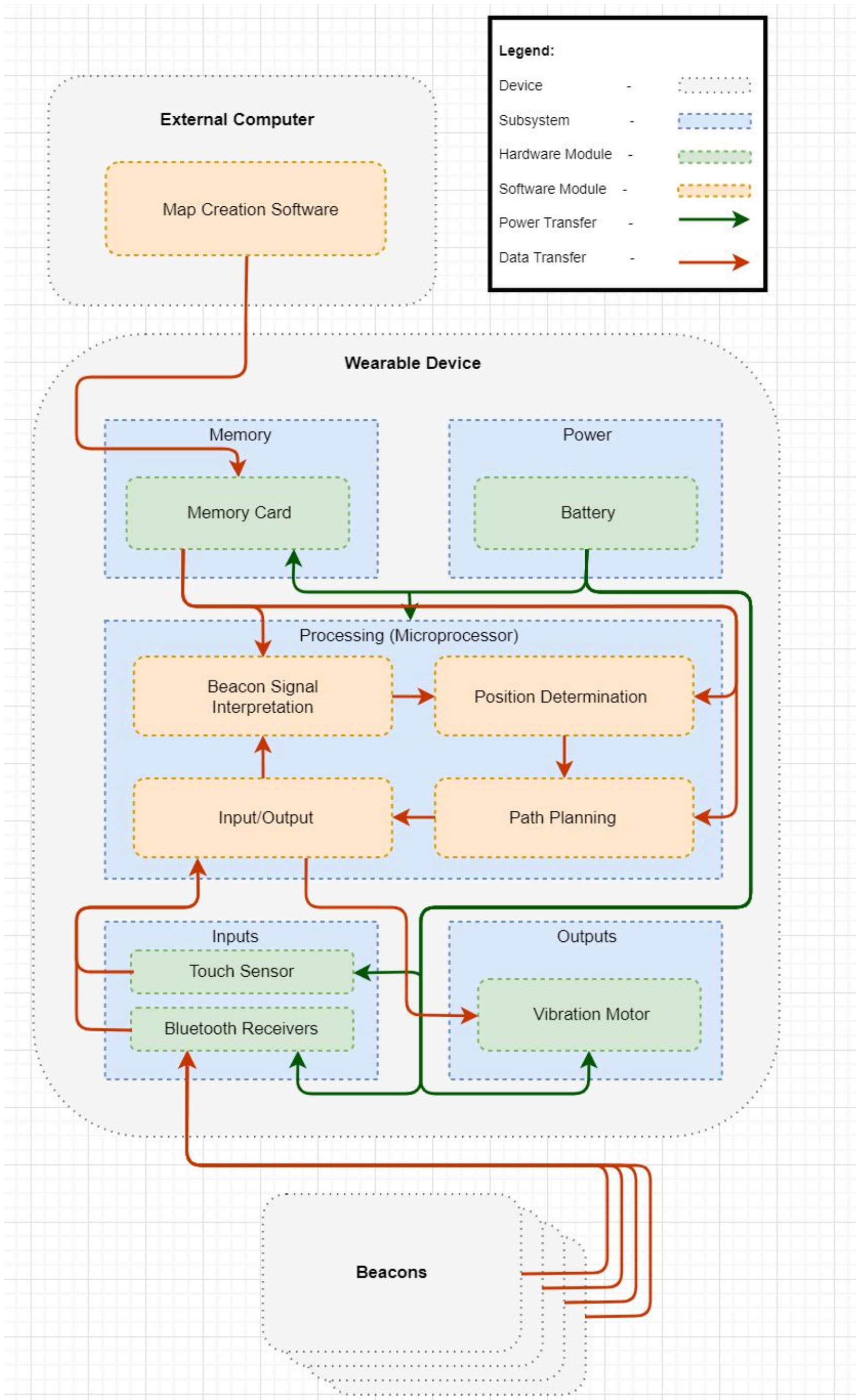
We plan on our application and wearable device being as compatible, cheap and user-friendly as possible to the blind person, especially from the guidance perspective. Moreover, we also have to keep in mind that there are no discrepancies or blind spots in location performance within our maps, when we position our beacons.

High-level Requirements List:

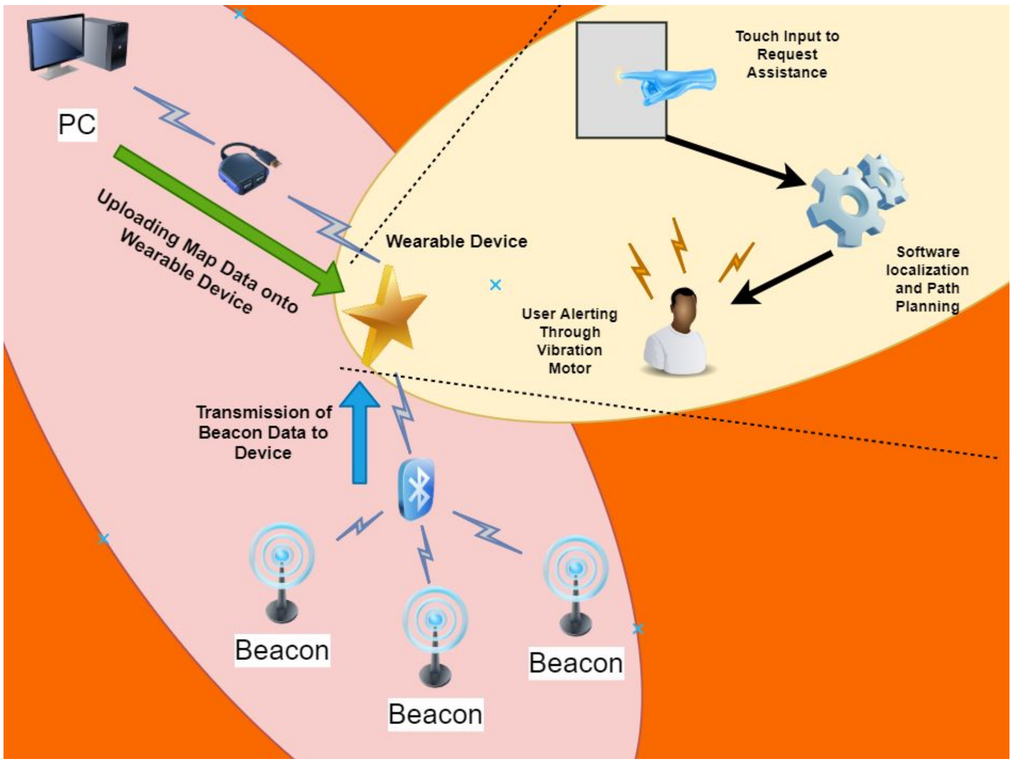
- Project must display proper functioning with at least 4 Bluetooth beacons, in order to prove the correct transition, as the user will be detected using the 3 closest beacons
- Proper functioning of vibration motor and touch sensor should allow for user to provide a destination to travel to and then receive appropriate instructions from the system regarding the path until the person reaches the destination.

Design

Block Diagram:



OV-1 Diagram:



Our block diagram consists of the several modular components within our system, and how they interface with each other. After formulating the walkability map on an external computer, we plan to put this information on a SD card, which will then be attached to our microprocessor. Once the user turns on the Bluetooth receiver to communicate with the 3 strongest beacons and inputs the destination point using the touch sensor, this information will be sent to the microprocessor, where all of the software processing will be carried out. This is sent back to the I/O interface, where the user will be notified of navigation errors using the vibration motor. This is conveyed in a straightforward manner by the OV-1 diagram above.

Physical Design (if applicable):

Above is the diagram of the Input/Output interface available to our users. Our vision for our prototype is a physical model, which will roughly resemble the setup seen above. Essentially, on the left is the Bluetooth receiver communicating with the strategically placed beacons. The vibration motors serve to alert the user of the path. The touch sensor is an input system for the user to pick the destinations- numbers of taps will correlate with different destinations. In our first prototype, we plan on uploading a walkability map onto the application beforehand.

Functional Overview:

Map Creation Software

The map creation software is responsible for creating a walkability map of the entire floor with obstacles, and clearly marked walking areas. Moreover, the map will also contain the positions of the beacons. These informations should be properly indexed by different locations and beaconIDs and then stored in SD card. The SD card will then be manually loaded into the device. Currently, we are manually loading these things, however, in the future we want to automate this so that this information can be directly sent to the device through bluetooth.

Memory Card

This module will store all the information (map, beacon positions and information etc.) that will be required to run the navigation. Since there will be multiple locations, there will be different maps stored in the SD card. When a particular beacon will connect to the system, the map belonging to that location will be used.

Battery

This will provide power to the whole system, comprising of the microcontroller, touch sensor, vibration motor, and Bluetooth receivers communicating with the beacons.

Beacon Signal interpretation

This Module will be responsible for choosing at least three beacons with the strongest signals and perform all the necessary preprocessing before sending it to the next block where they will be used to determine the position of user.

Position Determination

This beacon solves the trilateration problem in 2D space, with given bluetooth strength signals from three beacons and their respective absolute locations in the walkability map. It will also perform any coordinate transformations and corrections if necessary before sending the absolute coordinates to the Path Planning Module.

Path Planning

This module has inputs the walkability map, and the position of the user from the Position Determination block. This block will find the safest path from the user's current position to their specified destination. After finding the path, the block is responsible to communicate the next series of steps to the user in an understandable way i.e. converting the path into vibrational feedback so that the user can understand and then act. After the conversion, this new information will be sent to the output block so that it can be relayed to the vibrational motor.

Input/Output

This block is responsible to communicate with the touch sensor and the bluetooth receivers. It will also activate the vibration motor after parsing the information from the path planning module.

Touch Sensor

This block serves as one of the inputs interfacing with the user. For the purpose of our prototype, the feedback received from the user will determine the choice of destination on the walkability map. This information is then outputted to the I/O module within the microprocessor, which is then processed in the beacon signal interpretation block in order to determine the user's starting and end point. At this point of our project, we are using a touch sensor to relay feedback through physical taps on the sensor. Beyond the scope of this semester, we expect to convert this input feedback into a voice processing system, in order to facilitate the process for our users.

Bluetooth Receivers

This block serves as the other input interfacing with the user. The way we envision this block is that once the user is at their location (mall, airport, etc.), they will turn on this bluetooth receiver on their wearable sensor. Once this is done, the bluetooth receiver will immediately communicate with the beacons installed around their surroundings. After processing is completed, this module will enable the user's location to be detected by using the three strongest beacon values.

Vibration Motor

This block serves as the primary output module interfacing with the user. Once the path planning module determines the optimal path from the user's starting point to the destination point, that information is conveyed to the microprocessor's I/O module, which is then relayed to the vibration motor. We envision this module to provide vibrations to the user, whenever the user is starting to walk off path. Ideally, we would like to characterize this as every time the user takes a step which takes them farther away from the destination would warranty a vibration. Therefore, by notifying the user this way, it will help bring corrective action from the user.

Beacons

The beacon module will consist of at least 4 beacons for our prototype, in order to show the transition from the first 3 closest beacons to the next 3 closest beacons, as the user makes his/her way to the destination point. This module will communicate with the bluetooth receiver present on the user's wearable product. As we communicate data through our pipeline, each beacon signal strength will be tracked, in order to ensure only the 3 strongest ones are used to triangulate the user's location.

Block Requirements:

Bluetooth beacons (expect to use at least 4)
The placement and type of these beacons will be critical to the accuracy of the location of the user. We aim to have at least 4 beacons setup and simultaneously running.

Requirement 1: Should be based on the Bluetooth 4.0 or 5.0 module since it generally just a open-space indoor range of 400m, has lower power consumption and is intended for devices that only need to exchange small amounts of data periodically.
Requirement 2: Bluetooth devices' range heavily depends on the surrounding and can be affected by concrete walls so the device should be designed for indoor usage. It should be a BLE (bluetooth low energy) beacon that sends out signals in a radius upto at least 30 meters.
Requirement 3: Must work through battery. No continuous charging should be required. Preferably AA/AAA or lithium coin batteries.
Requirement 4: Advertising packets must comply with the Eddystone-UID/URL or the iBeacon Format so that we don't have to worry about different packet structures (these two formats are similar to each other). This is extremely important if we want to communicate with multiple beacons seamlessly.

Bluetooth Receiver
The receiver is incredibly important for our system since bluetooth range depends on the device and the strength of the receiver. In the future, we might use the receiver to also receive map data therefore a high quality receiver is desirable- for this project we are going to manually upload the maps into the SD card through an external computer.

Requirement 1: The range should be at least greater than 30 meters indoors since that will the minimum distance of the beacons.
Requirement 2: Should be compatible with microcontrollers such as ATMelga23 microcontroller and should operate using the Bluetooth Serial Port Protocol.
Requirement 3: Low power device 1-4V.

Vibration motor
The vibration motor will be responsible to providing feedback to the user.

Requirement 1: Must work within 1-6V.
Requirement 2: Should be small enough to vibrate and fit in a pocket or on the hand.

Touch sensor
The touch sensor is how the blind person will provide feedback to the device. In the future we want to convert this into a voice activated system however, for this project the touch will determine the destination that the map leads to.

Requirement 1: Should only be able to draw at most 5V since, we don't want to draw too much power on the touch sensor.

SD Card
The microSD Card will store the maps, the beacon locations, and other relevant information related to the user.

Requirement 1: The SD Card must easily fit and integrate into the microprocessor.

Microcontroller
The microcontroller will consist of our core software processing, which comprises of the beacon signal interpretation, solving the trilateration problem, and the path planning module. Additionally, it also contains the I/O module interfacing with the inputs and outputs present on the user's wearable system. The microprocessor will be powered by the battery and will draw input from our SD card. Our chosen microcontroller for this project will likely be the ATMega32, which will serve as the processing unit between the hardware and software modules, as well as the battery and SD card.

Requirement 1: Should draw about 2.7 - 5.5 V during operation
Requirement 2: The microcontroller should be able to compute the path in a reasonable (a few seconds) amount of time.

External Map Creation Software
This will be required to create offline maps, beacon locations and will be the only place where we can edit stored information on the SD card. In the future, we want to create a system where maps will be uploaded directly to the device through bluetooth.

Requirement 1: Must be bluetooth enabled to upload data through bluetooth to the microcontroller. Note: For future purposes only, currently the data will be loaded manually to the SD Card.

Power
The battery will power the microprocessor, touch sensor, vibration motor, and the Bluetooth receiver.

Requirement 1: The battery voltage will within a 3-10 V range, depending on the hardware component selections.

Risk Analysis:

Our project is made up of several key modules that need to align together in order for us to deliver a properly functioning end product to the user. We believe that the block posing the greatest risk to successful completion of the project is the path planning module. First of all, the path planning module is the interface that takes our project from being a location-tracking system to a navigation system. Therefore, we have to ensure that the path planning component is functioning as intended. The input to our path planning module will the user's coordinates and the destination coordinates. This will pose a big challenge as this module will need to relay the output coordinates with respect to the three beacons to coordinates on the map. We expect to deal with calibration issues while ensuring that the coordinates align. Additionally using a shortest path algorithm such as Dijkstra or BFS, we also need to then find a suitable path within the constraints of our walkability map. The output path must then be translated to directions that the user can understand via the vibration motor. Clearly, there are a lot of moving components within our path planning module.

Additionally, without the path planning module, our system will only be useful for keeping track of user's movements; the path planning module helps us take our product's functionality to the next level, as it would allow the visually impaired to comfortably and confidently navigate foreign public surroundings. This is also the part that differentiates our product from an indoor positioning product versus one that can navigate a blind person.

Ethics and Safety

During the development of our system, the main safety issue we will face will arise during the testing portion of our project. In order to ensure that our project is self-sufficient for our visually impaired demographic group, it is essential that the test subjects are emulating the equivalent conditions; for example, we will utilize a blindfold so that he/she will not be able to see. Since our project, at this point, will still be in development stages, the possibility of not detecting a completely accurate path to the destination is possible. Therefore, we have to ensure that our test subjects are safe and don't come under any duress in the case that the system guides them in an inaccurate manner. We can make sure of this by having someone be with the subject throughout the test, verbally/physically guiding the individual if needed.

During the use of our product, one potential concern is the fact that internal surroundings of viable locations could be slightly altered after uploading a blueprint to the system. Therefore, we must ensure that our blueprints are constantly being updated when major internal design changes are being made. Prioritizing this action will allow our users to have full confidence in our product. As seen in the IEEE Code of Ethics, the number one interest is to protect the safety and welfare of our users. Additionally, we want to update our blueprints when needed, as a means of transparency that we're doing our work on the back end. Moreover, it is vital that we market our product as a navigation tool which is meant to be utilized in supplement with regularly used walking aids. Industry-standard beacons tend to have a rough 1-2 meter inaccuracy, which would simply corrected by users having their canes/walking dogs/etc.

Lastly, users might be worried about their locations and privacy since they are being tracked in public areas such as malls, airports, etc. Our duty is to inform our users that the beacons are only communicating with their wearable sensors and that the data is not being sent elsewhere.

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