Virtual Vision: Autonomous Indoor Navigation System for Visually Impaired

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***Abstract*—This paper discusses the design and implementation of an enhanced indoor navigation system, aimed at improving existing technology by aiding the visually impaired. Loss of vision can drastically impair an individual's sense of direction and mobility, especially in unfamiliar surroundings. Due to this, visually impaired individuals often find themselves needing further support and time to gain familiarity with new indoor settings. The objective of this report is to present an enhanced indoor navigation system, customized to cater to the needs of the visually impaired. This has been achieved through the use of Bluetooth Low Energy (BLE) beacons, a BLE-supported Android device with in-built motion sensors, and an Android Mobile Application. The mobile application can be operated in three different modes – regular navigation, assisted navigation, and free-roam mode. The current implementation of the application supports navigation at Level 1 of the School of Computer Science and Engineering (SCSE). BLE beacons are placed at important landmarks of this environment, and the user is provided with a list of destinations for navigation. User interaction, feedback and the effectiveness of the proposed indoor navigation system have been evaluated in this paper.**

***Index Terms*— Bluetooth Low Energy, Received Signal Strength Indicator, Breadth-First-Search, Depth-First-Search, Dijkstra, Glonass- Global Navigation Satellite System**

I. INTRODUCTION

Over the past decade, the popularity of navigation tools as resources for accurate route planning and wayfinding has grown immensely. The major tools in the market today have enabled accurate navigation and demonstrated advances in path planning and movement control, and most importantly, in localization. Localization accomplishes the complex goals of accurate navigation by necessitating the support of precise topographic representation of space [1]. Localization can be broadly classified into outdoor and indoor variants. Outdoor localization has experienced a surge in technological advancements, as traditional celestial navigation techniques have grown to depend on satellites, such as – Global Positioning System (GPS), Galileo, and the Global Navigation Satellite System (GLONASS) [2]. The needs of these modern outdoor localization techniques have been met through efficient data collection using mobile mapping technologies and advancements in modelling and data storage. This has led to outdoor navigation becoming ubiquitous, with GPS receivers included in a variety of consumer electronic devices such as smartphones and tablet computers. Innovations in outdoor navigation systems have encouraged researchers to explore indoor navigation techniques to assist pedestrians in finding their way through complex indoor environments such as airport terminals, subways, and retail malls. GPS signal blockages by building walls and ceilings and multi-path interferences have increased the complexity of indoor navigation systems. As a result of this, the plethora of such existing systems rely heavily on electromagnetic signals, which are customized on the basis of their range, accuracy, and their capacity to penetrate solid objects [3]. One of the fundamental techniques for indoor localization is the use of Wireless Local Area Networks (WLAN). Wi-Fi technology, in particular, is frequently used for this purpose, where an accuracy of several decimetres has been achieved. Radio-Frequency Identification (RFID) is another option for highly accurate indoor localization, primarily up to several centimeters if smart floors are used [4]. an indoor navigation system, consisting of a client-side Android Application and a cloud based server. The application serves the purpose of providing both map-based visual indoor navigation as well as auditory and kinaesthetic navigation for the visually impaired.

The Android smartphone application, Virtual Vision, interacts with FUJITSU FWM8BLZ02 BLE Beacons to aid in indoor navigation. The application is also connected to a remote Flask Server running on an Azure Cloud Virtual Machine (VM). The server functions as the 'brain' of the entire system, enabling real-time calculation of paths, distances, and directions for the Android client. The system in its entirety is able to perform the following features – Receive Instructions/Commands from the user via: User Interface (UI) input o Kinetic input Voice input Interact with the BLE beacons placed around the test area to: Retrieve the landmark in the closest proximity to the user Calculate the distance between the user and the retrieved landmark Perform obstacle detection to: o Warn the user under assisted navigation of obstacles in the path Provide Tactile and Audio feedback for the visually impaired users: Vibrate the phone to indicate the correct direction during navigation Give audio warnings and instructions using Text-To-Speech (TTS) to provide easier interaction with the application .Display an interactable map of the test area for visual navigation: Present a list of available locations the user can select and navigate to Update the map with markers of selected locations and the path calculated Provide written directions for navigation. the client-side Android application Virtual Vision, the remote Flask Server, and the BLE beacons. The purpose of the remote Flask server is to perform heavy, time-sensitive computations and reduce the burden on 4 Virtual Vision to provide a more seamless and real-time experience to the user. It has been developed using Python version 3.11 and has been converted to a docker image. This docker image has been uploaded on a Linux VM (Ubuntu Server 21 – Long Term Support (LTS)) on Azure Cloud. This is done to facilitate time-critical computations and communication. Virtual Vision has been developed in Kotlin (enter version) using Android Studio (enter version). The tables below depict the permissions required by the application as well as the hardware features the application needs to function on the user's Android device.

Fig. 1

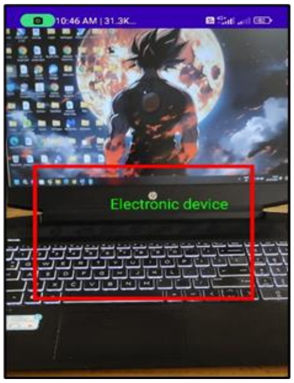


Fig. 2

II. EXISTING SYSTEM

There are various systems like smart canes, guide dogs, wearable devices, and indoor navigation tools that use sensors, AI, and GPS to help visually impaired individuals navigate autonomously. They detect obstacles, provide audio cues, and recognize surroundings to assist in safe movement. Enhancements focus on better object recognition, smaller devices, faster processing, and improved user interfaces for accessibility. While not autonomous in the technical sense, guide dogs are highly trained to assist visually impaired individuals in navigating their surroundings. They provide mobility support, avoid obstacles, and guide their handlers safely. These are traditional canes equipped with sensors or technology that can detect obstacles and provide feedback to the user through vibrations or audible cues. Devices like smart glasses or wearable cameras combined with artificial intelligence can recognize and provide audio cues about objects, people, or obstacles in the user's path. Using a combination of sensors, beacons, and smartphone apps, these systems help users navigate complex indoor environments like malls, airports, or public buildings. GPS-based apps can provide outdoor navigation by giving audio instructions for routes and points of interest. Improving these systems involves refining the accuracy of object recognition, reducing the device's size and cost, improving real-time processing speed, and enhancing user interfaces for better accessibility and ease of use. Integrating multiple technologies can create more comprehensive and reliable systems for autonomous navigation for the visually impaired.

III. PROPOSED SYSTEM

Creating an autonomous navigation system for the visually impaired involves combining various technologies to build a comprehensive solution. Here's a proposed system: Sensor Integration: Incorporate a range of sensors like ultrasonic, infrared, or LiDAR to detect obstacles and objects in the user's path. These sensors feed data to the navigation system. Computer vision and AI: Utilize cameras and machine learning algorithms to interpret visual information in real-time. This can identify objects, people, paths, and hazards. The AI processes this data to provide contextual information and generate navigation instructions. Wearable device: Develop a wearable device (such as smart glasses or a compact sensor equipped device) that integrates the sensors, cameras, and AI. This device communicates navigation cues to the user via audio signals or haptic feedback (vibrations) for obstacle avoidance and directional guidance. Navigation and Mapping software: Implement navigation software that integrates GPS data for outdoor navigation and mapping of indoor environments using beacons or other locationaware technologies. This software helps in route planning and assists in providing turn-by-turn directions.

IV. METHODOLOGY

Designing an Autonomous Indoor Navigation System for visually impaired individuals requires careful consideration of various factors to ensure its effectiveness and usability. Here's a methodology you could follow: 1. User Needs Assessment: Conduct interviews, surveys, or focus groups with visually impaired individuals to understand their specific navigation challenges and preferences. Identify common navigation scenarios such as finding exits, restrooms, stairs, elevators, or specific rooms within indoor environments. 2. Technology Review and Selection: Explore existing technologies and solutions for indoor navigation such as computer vision, RFID (Radio Frequency Identification), Bluetooth beacons, or LiDAR (Light Detection and Ranging). Select the most suitable technology based on factors like accuracy, reliability, costeffectiveness, and ease of integration with assistive devices. 3. Prototype Development: Develop a prototype of the navigation system integrating the chosen technology. This may involve hardware components (sensors, actuators) and software components (navigation algorithms, user interface). Ensure the prototype is compatible with existing assistive devices like smartphones or wearable devices commonly used by visually impaired individuals. 4. Environment Mapping: Create detailed maps of the indoor environments where the navigation system will be deployed. This may involve using mapping tools, surveying physical layouts, and annotating key landmarks and obstacles. Consider ways to represent the environment in a format accessible to visually impaired users, such as tactile maps or audio descriptions. 5. Navigation Algorithms Development: Develop algorithms for real-time localization and path planning within the mapped indoor environments. Consider factors like obstacle avoidance, route optimization, and user preferences (e.g., avoiding crowded areas, minimizing stairs). 6. User Interface Design: Design a user interface that provides intuitive feedback and guidance to visually impaired users. Consider auditory cues, haptic feedback, or tactile interfaces for conveying navigation instructions and alerts. 7. Accessibility Testing: Conduct usability testing with visually impaired individuals to evaluate the effectiveness and usability of the navigation system. Gather feedback on navigation accuracy, ease of use, clarity of instructions, and overall user experience. Iterate on the design based on testing results and user feedback to improve accessibility and user satisfaction. 8.Integration with Assistive Devices: Ensure seamless integration of the navigation system with existing assistive devices commonly used by visually impaired individuals, such as smartphones or wearable devices. Provide clear instructions for installing and using the navigation system alongside assistive devices. 9.Pilot Deployment and Evaluation: Deploy the navigation system in real-world indoor environments, such as public buildings, offices, or educational institutions. Monitor system performance, collect usage data, and gather feedback from users and stakeholders. Evaluate the impact of the navigation system on users' independence, mobility, and quality of life. 10. Iterative Improvement: Continuously gather feedback from users and stakeholders to identify areas for improvement. Iterate on the design, algorithms, and user interface based on real-world usage and evolving user needs. Stay informed about advancements in technology and accessibility standards to enhance the navigation system over time. By following this methodology, you can develop an Autonomous Indoor Navigation System that effectively supports visually impaired individuals in navigating indoor environments with greater independence and confidence.

V. SYSTEM ARCHITECTURE

The system architecture in Figure 3.1 illustrates how all the components are connected to each other. The user interacts solely with the client-side Android application via audio or UI input. In the above architecture, the client will be connected to the server via a WebSocket connection. The backend of application will initiate a connection with the Python WebSocket and start communication once the user has given instructions to the application. For the detection of BLE beacons, the Bluetooth manager of the smartphone will initialize the scanner and start scanning for nearby beacons. This architecture solely relies on BLE beacons for indoor navigation. Based on the BLE beacon detected, along with its fingerprint data, the server will calculate the shortest path to the chosen destination in real time. It relies on basic RSSI-distance calculations to estimate the distance to the next beacon/node

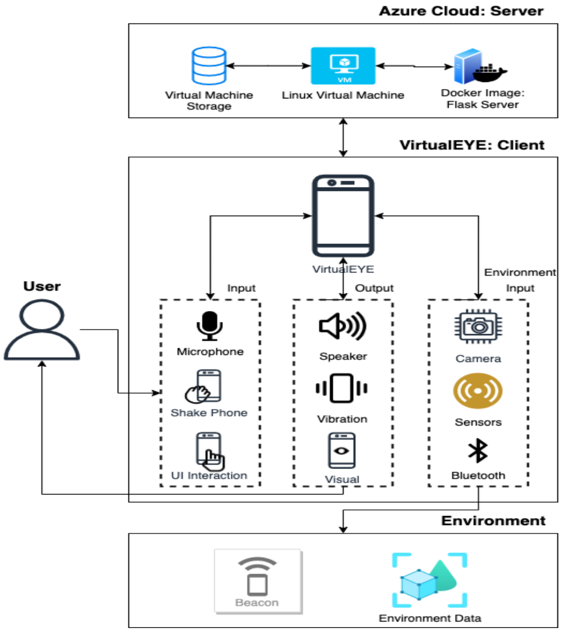


Fig. 3

VI. CONCLUSION

Loss of eyesight can drastically impair an individual's direction and mobility, especially in unfamiliar surroundings. While canes are an excellent modern tool for the visually impaired, they require additional assistance to be useful in new indoor settings. An indoor navigation system, comprising of an android application Virtual Vision, was built to complement existing mobility tools (canes). The system was designed to allow both the visually impaired and abled individuals to be able to navigate uncharted indoor settings independently. The system made use of BLE beacons to localize and navigate the user. Additionally, Virtual Vision also performed computer vision-based obstacle detection to provide additional feedback to its blind users. Current indoor navigation solutions are not wholly inclusive of the needs of visually impaired users. They fail to address the problems of accurate, non-visual landmark recognition and obstacle detection. Virtual Vision addresses these problems and extends the indoor navigation functionality for its blind users. The different forms of feedback given by the application (audio, tactile) also differentiates Virtual Vision from its competitors. Finally, the system architecture has been designed to make the functionality scalable and deployable. Virtual Vision is a lightweight user-end application that is independent of the location. The server has been designed as an HTTP API endpoint, whose functionalities can be extended for multiple use cases. Employing wearable technology (smartwatch) can reduce the load from the mobile application and provide more feedback to the visually impaired user. This can enable the navigation system to use additional sensor data from wearable technology to help localize and provide useful information about the user’s surroundings. It will also reduce the need to hold the phone during navigation. Visual Positioning System (VPS) is a rapidly evolving technology in the field of computer vision and artificial intelligence. This method of localisation can be employed with BLE beacons for more accurate results for the user. Training models on environment images can be used to create a co-ordinate system for path planning algorithms and hence navigation.

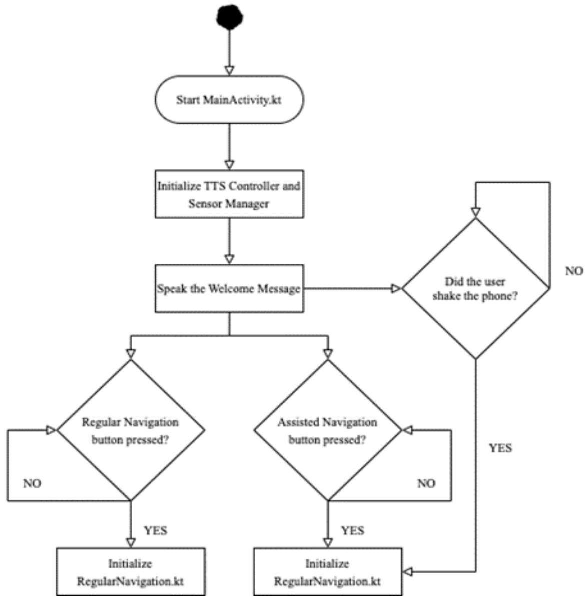


Fig. 4

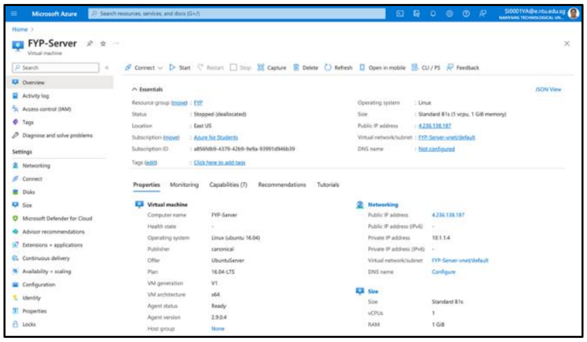
APPENDIX

1. Home screen of the Application provides User interface and functionalities like Haptic feedback using Vibrations and text to Speech.
2. Regular Navigation Mode: Provides Features such as Map and Compass, Realtime directions.
3. Regular Navigation Mode: Selecting the Desired location.
4. Regular Navigation: Directions and Map Display.

Fig. 5

5. Free Roam Mode: Obstacle Detection.

6. Assisted Navigation: Get User Input
7. Assisted Navigation: Navigate User Screen.
8. Server: Cloud VM and Output on Request



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Status : Stopped (deallocated)
Location : East US
Subscription (move) : Azure for Students
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Tags (edit) : Click here to add tags
Operating system : Linux
Size : Standard B1s (1 vcpu, 1 GiB memory)
Public IP address : 4.236.138.187
Virtual network/subnet : FYP-Server-vnet/default
DNS name : Not configured

Computer name FYP-Server
Health state -
Operating system Linux (ubuntu 16.04)
Publisher canonical
Offer UbuntuServer
Plan 16.04-LTS
VM generation V1
VM architecture x64
Agent status Ready
Agent version 2.9.0.4
Host group None

Public IP address 4.236.138.187
Public IP address (IPv6) -
Private IP address 10.1.1.4
Private IP address (IPv6) -
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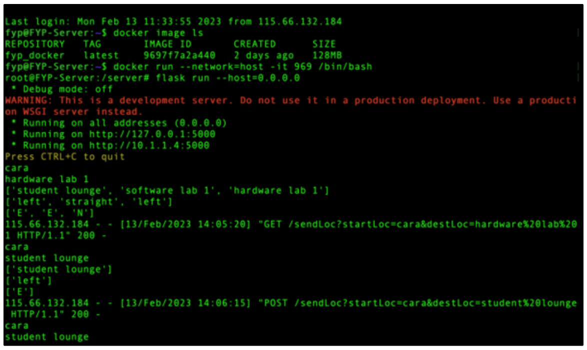
DNS name Configure

Size Standard B1s
vCPUs 1
RAM 1 GiB

Fig. 6



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Last login: Mon Feb 13 11:33:55 2023 from 115.66.132.184
fyp@FYP-Server:~$ docker image ls
REPOSITORY   TAG       IMAGE ID       CREATED      SIZE
fyp_docker   latest    9697f7a2a440   2 days ago   128MB
fyp@FYP-Server:~$ docker run --network=host -it 969 /bin/bash
root@FYP-Server:/server# flask run --host=0.0.0.0
 * Debug mode: off
WARNING: This is a development server. Do not use it in a production deployment. Use a producti
on WSGI server instead.
 * Running on all addresses (0.0.0.0)
 * Running on http://127.0.0.1:5000
 * Running on http://10.1.1.4:5000
Press CTRL+C to quit
cara
hardware lab 1
['student lounge', 'software lab 1', 'hardware lab 1']
['left', 'straight', 'left']
['E', 'E', 'N']
115.66.132.184 - - [13/Feb/2023 14:05:20] "GET /sendLoc?startLoc=cara&destLoc=hardware%20lab%20
1 HTTP/1.1" 200 -
cara
student lounge
['student lounge']
['left']
['E']
115.66.132.184 - - [13/Feb/2023 14:06:15] "POST /sendLoc?startLoc=cara&destLoc=student%20lounge
 HTTP/1.1" 200 -
cara
student lounge
```

Fig. 7

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