A Wayfinding Mobile Application for Visually Impaired Users in Wellington Regional Hospital

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***Abstract*—Navigating large and complex hospitals such as Wellington Regional Hospital can be challenging, leading to patients missing appointments and wasted staff time. This problem is particularly acute for visually impaired people who may require additional assistance with wayfinding. This project proposes a wayfinding mobile application to enable interactive navigation for both visually impaired and non-impaired users at the Wellington Regional Hospital. The project focusses on the development of a sophisticated location positioning algorithm, turn-by-turn directions, and a new mapping service in the pre-existing application. The positioning algorithm leverages trilateration of Bluetooth beacons in conjunction with pedestrian dead reckoning (PDR), enabling the integration of accurate turn-by-turn navigation and immersive audio prompts. Evaluation shows that the proposed application can reduce navigation time by up to 50%.**

***Index Terms*—Bluetooth Low Energy, Android, Mobile Applications.**

I. Introduction

HOSPITALS can be very difficult and confusing to navigate, and visitors can get lost easily, resulting in missed appointments. This not only causes inconvenience for patients and visitors but also consumes valuable staff time as they assist in giving directions. In the case of Wellington Regional Hospital, the situation is made worse by ongoing refurbishments and the addition of new buildings. Moreover, navigation proves to be particularly problematic for visually impaired people who may need additional help with navigating.

The goal of this project is to design and develop a mobile application to enable interactive wayfinding for both visually impaired and non-impaired users. This project is a continuation of a previous project, however, the mapping software the previous application used is no longer available. Therefore, this project aims to re-develop the wayfinding application, with the addition of turn-by-turn navigation and audio prompts. The outcome of this project was evaluated by visually impaired users. It is important to evaluate the application to understand any areas that could be improved, especially for vision-impaired users. Software and hardware resources were provided by Te Whatu Ora, Capital, Coast and Hutt Valley (CCHV), and the supervisors.

The proposed application's evaluation demonstrated an accuracy of 1.33 metres, placing it comfortably within the benchmark set by existing solutions, which typically achieve accuracies of less than four metres [1], [2]. User evaluation found that the application reduces navigation time by up to 50%.

A. The Problem

As seen in Figure 1, Wellington Regional Hospital is large with complex buildings and many levels. This creates a significant challenge for patients and visitors to navigate. This results in patients arriving late or seeking assistance from staff members to find their way, resulting in a waste of valuable time for patients and staff members. A study by Craig Zimring from the Georgia Institute of Technology found that problems with wayfinding at Emory University Hospital cost the hospital approximately $350,000 NZD annually [3]. This problem is especially of concern for visually impaired people who cannot easily look at a map and navigate themselves. Additionally, inaccurate and outdated maps within the hospital only add to the confusion experienced by patients. With approximately 30,000 individuals in New Zealand living with a visual impairment or low vision [4], the added challenge they face in navigating a busy hospital highlights the need for a tailored application to address their requirements.

The pre-existing application designed by previous Victoria University of Wellington (VUW) student, Nevin Jojo, allowed users to get an overview of their route but it critically lacked turn-by-turn navigation. This was attributed to the high level of precision needed in the calculations to obtain a location point which required more Bluetooth Low Energy (BLE) beacons, which were not available at the time of the previous project. Therefore, only an algorithm to get the localisation area was implemented. This means that the application was not as useful for people with major vision impairments as

This project was supervised by Alvin Valera, Jyoti Sahni, and Kenny McCaul (Head of Contracted Services at CCHV)

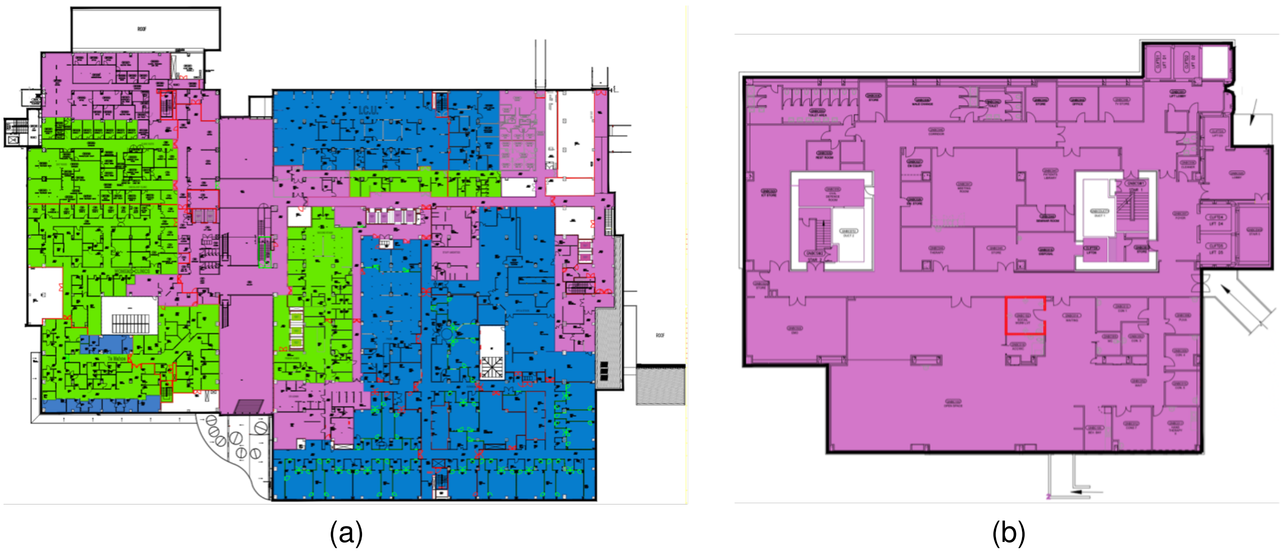

Fig. 1. Floor Plans of Wellington Regional Hospital Level 3 [5]. (a) Main Block. (b) Grace Neill Block

it was for people with minor impairments. To implement turn-by-turn navigation, more BLE beacons have been purchased by CCHV since the conclusion of the previous project.

Additionally, there were some issues with the pre-existing application. The pre-existing application used Mapwize to map the interior of the hospital and to get the route overview from locations to points of interest, however, this software is no longer available [6]. This required developing a new map functionality in the application that is capable of displaying routes.

B. Scope

The primary objective is to produce a user-friendly and accessible turn-by-turn wayfinding application for use inside Wellington Regional Hospital. The application aims to provide a positive experience for patients and visitors, increased efficiency for staff members and ultimately, a positive impact on the overall quality of care provided at the hospital. The application will be usable by both visually impaired and non-impaired users. Turn-by-turn navigation is provided both on the device screen and via audio prompts. The pre-existing application already incorporates an accessible design, eliminating the need for reinvention and allowing dedicated efforts to enhance the accuracy of indoor positioning calculations for the turn-by-turn directions.

To address the need for a comprehensive overhaul of the application's key mapping component, coupled with the integration of a more sophisticated location positioning algorithm, it was determined that testing should be conducted at VUW. This decision aimed to focus on the development by minimising the time spent on frequent trips between Wellington Regional Hospital and VUW for implementing application changes. The application was designed with modularity in mind so that it can be adapted for use at Wellington Regional Hospital in the future - see Section IV for more information.

A route from Cotton Level 2 to the Engineering and Computer Science (ECS) office was used to best mimic a route at Wellington Hospital as it consists of multiple levels and intersections. Focusing on one specific route ensured that sufficient time was dedicated to the development of the turn-by-turn calculations, allowing for careful consideration and attention to detail.

C. Sustainability

The overarching objective of this project is to improve equity between visually impaired and non-impaired individuals by developing an indoor wayfinding solution specifically designed to cater to the unique requirements of those with visual impairments. In developing this application, not only does it have the potential to significantly enhance the navigational experiences of visually impaired users, but it also aligns with the United Nations' Sustainable Development Goal 10, which emphasises the reduction of inequalities [7]. This alignment highlights the broader societal and global significance of the project, extending beyond the immediate context of Wellington Regional Hospital. Furthermore, in ensuring the long-term feasibility and impact of the application, sustainability has been considered in both the design and implementation, discussed in Sections III and IV.

II. BACKGROUND

The development of an efficient and user-friendly application for visually impaired users requires a comprehensive understanding of existing solutions, suitable methodologies, and available tools. This section explores the background research, examining the current state of wayfinding solutions and methodologies utilised in similar projects. It also explores the various tools and frameworks that can support the development process, including options for calculating location using BLE beacons and selecting mapping services.

A. *Current Wayfinding Solutions at Wellington Regional Hospital*

This project explores the two main Wellington Regional Hospital buildings which house the majority of services, the Main Block and the Grace Neill Block, as depicted in Figure 1. The third floor of these buildings is connected by a link bridge, facilitating navigation between the blocks without the need to step outside. Patients and visitors must pass through multiple doors and utilise multiple elevators to reach the Eye Clinic from the Level 2 entrance. Wellington Hospital corridors are often long, lack signage in certain areas, and outdated signage fails to reflect clinic relocations or additions. Figure 2 displays an example of the current wayfinding solution at Wellington Hospital, which consists of two-dimensional maps and signage. Due to these being static, they lack flexibility for updates following renovations. Some existing maps show outdated information, with certain areas left blank or displaying inaccurate details.

Fig. 2. Existing Signage at Wellington Regional Hospital [5]

An analysis of commonly used routes reveals a frequent change in direction when navigating between facilities, resulting from extensive hospital renovations and expansions [8]. Consequently, hospital staff often find themselves providing directions to disoriented visitors, highlighting the need for an improved wayfinding solution to enhance navigation efficiency and alleviate staff workload.

B. *Related Work*

In the sector of wayfinding in busy areas, such as hospitals, several mobile applications have emerged to provide solutions. Notably, WayStride and Situm are two such applications that aim to assist users in navigating complex environments. By examining these existing solutions, valuable insights can be gained into their functionalities, features, and limitations, which will inform the development of this project tailored to the specific needs of CCHV.

1) WayStride: WayStride is a mobile application designed to provide users with a stress-free navigation experience within the Washington Health System Hospital. It is designed to enable users to confidently navigate their way around the hospital without the need to rely on staff assistance or complicated maps. The application utilises advanced location capabilities to pinpoint the user's exact location within the hospital which enables a detailed step-by-step route upon inputting their appointment location [9]. Furthermore, the application assists users in efficiently locating wards and other essential areas located within the hospital and facilitates the identification and locating of hospitals from the outside, making it a versatile tool that provides navigation both inside and outside the hospital. Although, the application offers user-friendly features such as the ability to remember where the user parks or guidance to the best parking area, there is still a lack of accessibility features to cater to those who are visually impaired and may need further assistance to get to their appointment.

2) Situm: Situm is a company that specialises in indoor positioning and mobile wayfinding solutions. The platform is similar to WayStride as it offers real-time positioning, turn-by-turn navigation, and route planning. The technology consists of a combination of sensors, Wi-Fi signals, and BLE beacons to determine a user's precise location within an indoor environment [10]. Situm also provides an open-source mobile application that uses the Situm Software Developer Kit (SDK) for wayfinding, although it is worth noting that access to the Situm SDK requires a paid subscription. The SDK offers a wide range of accessibility features including text-to-speech, speech-to-text, and zoom controls. These accessibility features cater to visually impaired users and are very similar to the accessibility features of the CCHV wayfinding application.

C. Indoor Positioning Methodology

Today's mobile devices incorporate a wide range of sensors, enhancing their perception and analysis of indoor environments; however, for accurate indoor positioning, certain factors need to be considered. These factors include signal interference, overlapping beacon broadcasting regions, and indoor map quality [11]. There are many pre-existing indoor positioning technologies to calculate positions such as Bluetooth, ZigBee, WiFi, and UWB [12]. When evaluating various indoor position technologies, several aspects must be taken into account. These include positioning accuracy which measures the difference between the estimated and actual target positions, and environmental adaptability which refers to the algorithm's ability to handle multiple targets and various scenarios. Additional factors include real-time performance, installation and configuration time, and power consumption [12]. After evaluating such factors, BLE beacons are a promising method as they can be flexibly deployed, offer quick and real-time acquisition of target locations, and are relatively easy to maintain at a low cost due to their low power consumption [11], [12]. This low power consumption contributes to reduced energy usage and overall environmental sustainability, which aligns with worldwide sustainability goals such as responsible consumption and production [7].

Three methods that will be explored for estimating the position of a mobile device with BLE beacons are Received Signal Strength Indicator (RSSI) fingerprinting, triangulation and trilateration. These are among the most popular techniques [13] that offer various approaches to determine the location of the device based on the RSSI received from the BLE beacons.

1) RSSI Fingerprinting: RSSI fingerprinting estimates the location of a mobile device based on the RSSI from nearby beacons [14]. It involves creating a reference database of RSSI values at various known locations within the hospital during the calibration phase. These measurements are associated with their corresponding locations and stored in a database. When the mobile application is in operation, the application measures the RSSI values from the surrounding beacons. These values are then compared to the fingerprints in the database to determine an approximate location for the device. This method appears to be a suitable option, given that studies have demonstrated RSSI fingerprinting to excel in comparison to trilateration and triangulation, particularly in intricate environments such as hospitals where signal interferences pose significant obstacles [1], [13]. However, this approach requires a regularly updated fingerprint database that accommodates environmental changes, including common occurrences such as refurbishments, which are often observed in hospital settings.

Although RSSI fingerprinting has its downsides, such as being sensitive to environmental changes, it has been found that combining it with pedestrian dead reckoning (PDR) can greatly improve this indoor positioning method [15]. By leveraging the strengths of both techniques, the system can reduce the limitations of RSSI fingerprinting while enhancing its accuracy and reliability. PDR is a self-contained technique that relies on the calculation of step length, walking direction, and step size using inertial sensors (such as accelerometer, gyroscope, and magnetometer) [16]. These sensors enable the estimation of movement-related data and positions for the mobile device. Due to its reliance on motion sensors such as accelerometers and gyroscopes, PDR can be susceptible to drift and noise from these device sensors. Over time, these factors can accumulate leading to imprecise position estimates, resulting in inaccuracies [16]. These limitations can be mitigated by integrating PDR with another algorithm such as RSSI fingerprinting [15]. PDR can provide real-time user locations, while RSSI fingerprinting can help reduce errors by verifying the estimated position with the corresponding RSSI fingerprints.

2) Triangulation: Triangulation is a geometric method used to determine the position of a mobile device by measuring the angles from at least three known points [17]. These measured angles are then used to calculate the position of the mobile device using trigonometric principles. Figure 3 shows how triangulation is accomplished with three beacons B_1, B_2 and B_3. To perform triangulation, it is essential to know the locations of at least three of the beacons and the corresponding angles from the mobile device to those beacons. With this information, trigonometric principles can be applied to calculate the lengths of the missing sides, representing the distances from the beacons to the mobile device. By using these calculations, the precise location of the mobile device can be determined.

Achieving optimal accuracy using triangulation is challenging due to the calculation of the angles which must take into account the height of all beacons and mobile device, the direction of the mobile device, and the overlapping area of the beacon ranges [17]. Due to these challenging aspects and the limited timeframe this project permits, triangulation will not be used for the location calculation of the mobile device.

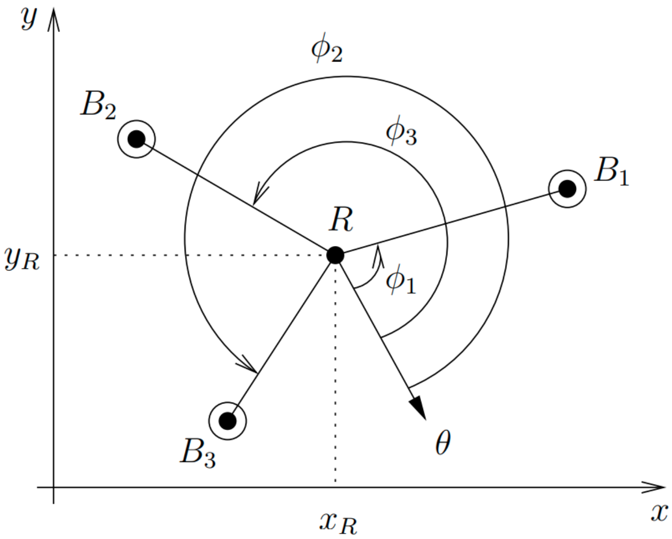

Fig. 3. Triangulation [17]

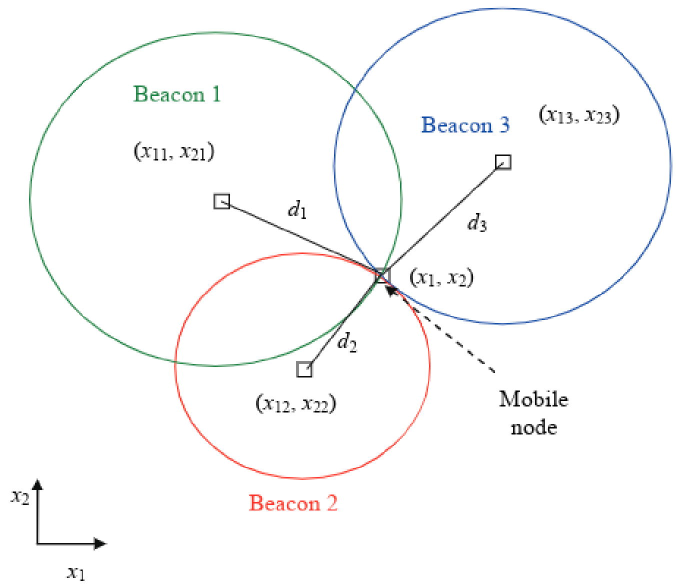

Fig. 4. Trilateration [18]

3) Trilateration: Trilateration measures distance rather than angles, determining the position of an object by utilising the known distances from at least three beacons to the mobile device [18]. By finding the intersection where multiple circles meet, trilateration can calculate the user's position.

As seen in Figure 4, to carry out trilateration the distances of at least three beacons to the mobile device are required. The distances from the mobile device to the beacons are represented by d_i, and the coordinates of the beacons are represented by x_{1i}, x_{2i} (where i = 1, 2 and 3). The localisation point between the three beacons can be determined using Pythagoras' theorem.

In the case of beacon trilateration, the distance from the device to each beacon can be estimated based on the RSSI of the beacons. One possible equation for the distance is shown in equation 1 [19].

$$d = 10^{\frac{\text{TxPower}-\text{RSSI}}{10n}} \tag{1}$$

In this formula, TxPower represents the beacon's transmission power, measured at a standard reference distance of 1 metre. This power value offers a benchmark, denoting the expected signal strength under optimal conditions at 1 metre. RSSI, or the Received Signal Strength Indicator, captures the observed power level of the received signal by the device. As a device moves farther from the beacon, the RSSI value tends to diminish. The constant n is the path-loss exponent. This value is dependent on the environment: while open spaces usually have a value close to 2, indoor settings can have higher values due to signal interactions with walls and other obstacles. The equation represents the inverse logarithmic relationship between RSSI and distance, encapsulating the effects of interference, absorption, and the environmental topology on the signal's attenuation rate [19].

If the calculated distances are accurate, trilateration can provide the exact location of the mobile device. However, it is difficult to achieve exact measurements of the distances based solely on the RSSI. Consequently, rather than a distinct point, the trilateration of beacons often determines a circle representing probable locations. By having a dense deployment of beacons, this results in a constricted area of the circle and therefore an increase in the accuracy of the location can be achieved.

D. Mapping Services

TABLE I
COMPARISON OF MAPPING SERVICES

Service	Route Display	Turn-by-Turn Directions	Free
Situm	Yes	Yes	No
ArcGIS	Yes	Yes	No
Mapbox	Yes	Yes	Yes

This section discusses multiple mapping services and their features as seen in Table I. The service must be low-cost and provide a way to display routes and turn-by-turn directions as these are required for the mobile application.

As mentioned earlier in Section II-B, Situm's open-source application was considered due to its wide range of wayfinding features such as real-time positioning, turn-by-turn navigation, and route planning. However, the mapping service that Situm provides is a paid service. Situm was contacted for a sales enquiry but they were not willing to give a price estimate so this is not being considered for the project.

Another indoor mapping provider is ArcGIS. ArcGIS is a widely used mapping service provided by Esri, a leading company in GIS (Geographic Information System) technology [20]. Much like Situm, ArcGIS offers real-time positioning, route planning and turn-by-turn directions. However, ArcGIS is also a paid service based on the size of the maps [20]. If this application were to be commercialised the costs associated with deployment could accumulate rapidly given the size of the hospital premises. As a result, a mapping service that aligns with the budgetary constraints of the project should be considered, such as Mapbox.

Mapbox offers a compelling set of features that fulfil the necessary requirements of the wayfinding application. Firstly, Mapbox provides a free tier option, allowing up to 10 monthly users without incurring any costs [21]. Mapbox also offers turn-by-turn navigation and robust route planning functionalities - allowing different routes based on various criteria such as distance, time, and accessibility. This feature enhances efficiency and ensures that users can easily navigate between different areas within the hospital. However, Mapbox does not provide real-time positioning. This is not an issue as this algorithm is implemented in the application as set out in Section III-A. Mapbox's free tier is sufficient for a prototype, however, if CCHV wants to provide this application to more than 10 users, they will have to upgrade to a paid subscription. This cost has been anticipated and agreed upon during the proposal phase of the project.

E. Mobile Development Frameworks

Several options for the development framework were evaluated, including React Native, Flutter, and Kotlin. Cross-platform frameworks such as React Native and Flutter are advantageous due to their ability to target multiple operating systems (OS). In particular, Flutter stood out for its focus on accessibility features [22], which aligns with the objectives of the project. However, preliminary research showed that Flutter does not have robust libraries for beacons [5], [23], which is a crucial requirement of the application.

While cross-platform frameworks offer the advantage of code reuse and faster development, they also come with certain limitations. For instance, there are not as many comprehensive mapping SDKs for React Native and Flutter compared to native languages like Swift for iOS and Kotlin for Android [21]. Additionally, developing for multiple devices can introduce complexities due to differences in each OS, adding unnecessary development time to the project. Therefore, the choice has been made to focus on a native framework.

Kotlin is a programming language used for the native development of Android applications. Native applications offer better performance than cross-platform applications due to being specifically designed and optimised for one OS. Kotlin offers extensive libraries for BLE beacon management which allows for seamless integration of beacon functionality. Additionally, Mapbox offers a robust Mapbox SDK for Android which is crucial for implementing the mapping service [21]. These libraries simplify development and ensure a high level of performance. Another key advantage of Kotlin is that the previous application was written in Kotlin, which means the existing user interface does not need to be rewritten and more focus can be on the development of the indoor positioning algorithm and turn-by-turn navigation.

III. Design

Given that this was a pre-existing project and CCHV is satisfied with the current user interface of the application, significant modifications to the interface were not expected. This section discusses the design of the application, including the choice of components and the system architecture.

A. Choice of Components

Section II discussed various approaches for location positioning, mapping services, and mobile frameworks. This subsection will discuss the specific components chosen for the application and the reasoning behind these choices.

The location positioning algorithm is a critical aspect of the application as it determines the reliability of the turn-by-turn directions. The pre-existing application estimated the area of the mobile device by finding the closest beacon to the mobile device through the RSSI values of nearby beacons and assumed that as the device's location [5]. The method of indoor positioning for this project takes a more sophisticated approach by using a combination of trilateration and PDR. This can now be accomplished through the recent acquisition of additional BLE beacons, enabling the deployment of more beacons for a larger coverage area. PDR has been shown to improve accuracy with an RSSI fingerprinting algorithm [15], and this project utilises similar logic by applying PDR to trilateration. Due to RSSI fingerprinting being sensitive to environmental changes such as refurbishments, the decision was made to implement PDR with trilateration to provide accurate and frequent location updates that are not as sensitive to environmental changes.

The mapping service is also a crucial aspect of the design as this is the component that visualises the maps and the routes. Given the previous information on mapping services, Mapbox is the most suitable choice for the wayfinding application due to its wide range of features and low cost compared to alternative services. By leveraging Mapbox's comprehensive mapping services, the application can provide an adaptable and cost-effective solution for wayfinding within Wellington Hospital.

The selection of an appropriate mobile framework is important as this determines which SDKs and libraries can be used to aid in application development. Given the previous evaluation of mobile frameworks, Kotlin was chosen due to its library support and compatibility with the pre-existing application. Although this means the application only caters for Android devices, this is adequate as CCHV does not have any preference for a targeted OS.

B. System Architecture

Figure 5 shows a system architecture diagram of how the application interacts with various components.

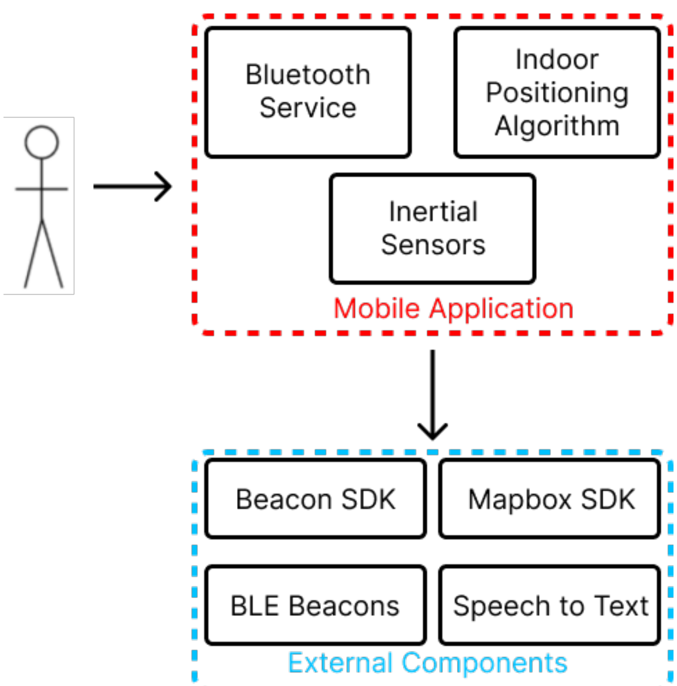

Fig. 5. System Architecture of the Application

As discussed in Section II, the proposed wayfinding application utilises BLE beacons for the location algorithm as they are low-cost, low-power, and easy to deploy which is important for a dynamic environment such as a hospital. Beacon deployment was minimised to reduce the number of redundant beacons. This aligns with global environmental and sustainability goals such as responsible consumption and production [7]. By optimising the placement of beacons, the number of redundant beacons can be minimised, thereby reducing unnecessary resource consumption. This approach contributes to sustainability efforts by ensuring efficient utilisation of resources and minimising the environmental impact associated with excessive beacon deployment.

The native Bluetooth service interacts with the beacons to retrieve their IDs and RSSI values. This, along with the mobile phone's inertial sensors (accelerometer and magnetometer) are utilised to implement the positioning algorithm. The indoor positioning algorithm is implemented into the mobile application itself so that no additional external services are needed. This algorithm consists of trilateration and PDR to achieve accurate and up-to-date locations. Furthermore, the mobile application uses the Mapbox SDK to interact with the external mapping service, providing a global map and producing visual and audio turn-by-turn directions to the user's destination. This offers valuable support for visually impaired users who may require auditory navigation cues. The Mapbox SDK determines when to trigger these directions based on the position of the user which is continually calculated by the indoor positioning algorithm. Finally, speech recognition components offered by third-party libraries are used to convert the user's speech to text, further enhancing the usability for visually impaired users. This mobile application was developed for Android because the previous application was written in Kotlin and Android has better support for Mapbox and beacon technologies, surpassing that of alternative operating systems explored during the research phase.

IV. Implementation

The design section previously presented an overview of the system architecture for the proposed wayfinding application tailored to aid both visually impaired and non-impaired users. This section will discuss the specifics of how each component was implemented to actualise this design.

A. Beacons

Indoor navigation poses unique challenges compared to traditional outdoor navigation due to the absence of accurate global positioning system (GPS) signals. To address this, BLE beacons have been deployed to enable accurate positioning indoors. The Kontakt Anchor

Beacon was selected during the previous project due to its ease of configuration, integration with third-party software, and deployment [5]. Kontakt beacons are a suitable choice for this wayfinding application as they offer reliability and comprehensive documentation for their Android SDK [24]. The Kontakt SDK was integrated to facilitate interaction between the mobile application and the beacons.

Beacon settings such as power level and advertising interval can be configured to optimise the performance of the beacons. The power level determines the strength of the signal transmitted by the beacon and ranges from zero to seven, with corresponding transmission levels of -30 dBm to 4 dBm [25]. The higher the power level, the higher the range of the signals and the better chance the signals have of cutting through interference [25]. The power levels of the deployed beacons were increased from three to seven to maximise the range of the beacons and reduce the risk of interference. However, this comes at a cost to the battery life of the beacon as higher power levels drain batteries faster. Conversely, the advertising interval determines how often packets are sent by the beacon. This has a default value of 100ms, which equates to ten packets a second. The advertising interval was increased to 350ms in an attempt to counteract the power level changes made earlier. The beacon scanner integrated into the application operates at a scan interval of two seconds. Therefore, extending this interval by an additional 250ms did not show any noticeable decline in performance. Kontakt states that an interval of 350ms will have an increase in battery life by up to 260% [26]. This is a significant increase in battery life and is a worthwhile trade-off for the slight decrease in packets being sent. Optimising battery life is not only important to reduce maintenance costs but also to reduce the environmental impact of the beacons. This aligns with global sustainability goals such as responsible consumption and production [7].

Beacon details such as their power level and transmission frequency can be configured using the Kontakt Cloud [27]. The Kontakt Cloud is a web-based platform that allows for the management of Kontakt beacons and their associated data. This includes the ability to configure beacon settings, monitor battery levels, and view beacon analytics. Kontakt also offers an SDK that allows for the retrieval of beacon information such as their IDs, RSSI values, and estimated distance from the mobile device. This information is crucial for the indoor positioning algorithm as it is used to calculate the device's location along the route.

The list of Kontakt beacons is stored in the Kontakt Cloud, and this list is retrieved when the application is loaded to ensure any change in beacon information is accounted for. This list is then used to implement beacon filtering. When beacon packets are received by the application, they are filtered to ensure that only beacons that are registered to the CCHV's Kontakt account are considered. This ensures that unauthorised beacons do not impact the location algorithm. A second filter is applied to only consider beacons that have a location assigned to them. Unfortunately, the Kontakt Cloud does not offer functionality to store latitude and longitude coordinates. Therefore, this requires a manual copy to be stored. This is not ideal as it requires storing information about the beacons in a second place, however, it is a viable solution until Kontakt implements such a capability. These coordinates are stored in the same file as the map to reduce the number of files that need to be loaded on the device.

B. Maps

In order to implement indoor navigation and indoor localisation, the application must display the floor plans of the indoor environment. Maps created as part of the pre-existing application were not available as they were created and stored in Mapwize which is no longer available. Therefore, new maps had to be created. As seen in Figure 1, the floor plans provided by CCHV contain detailed information such as inner walls, outer walls, direction of door openings, and room measurements. These details, while comprehensive, clutter the interface and are of limited relevance to patients and visitors. In addition, the colour scheme used in these floor plans is not relevant for indoor navigation and poses a potential difficulty to visually impaired users. Therefore, new maps were created for simplicity and accessibility for visually impaired users. To ensure the flexibility and long-term viability of the maps, the GeoJSON format was used for their creation. GeoJSON, being a widely accepted mapping format, offers the advantage of transferability in case the chosen mapping service becomes obsolete. This allows for seamless migration of the maps to a new platform if needed. Additionally, GeoJSON's versatility facilitates the easy creation of new maps, which is crucial for accommodating the dynamic nature of Wellington Hospital, with its ongoing changes and refurbishments.

Wellington Regional Hospital maps were supplied in DXF format which is an AutoCAD file. Unfortunately, there were no coordinates with the supplied DXF files so these had to be manually mapped. These were converted using AutoCAD and a tool called DXF to GeoJSON [28]. To enhance the legibility of the floor plan, the

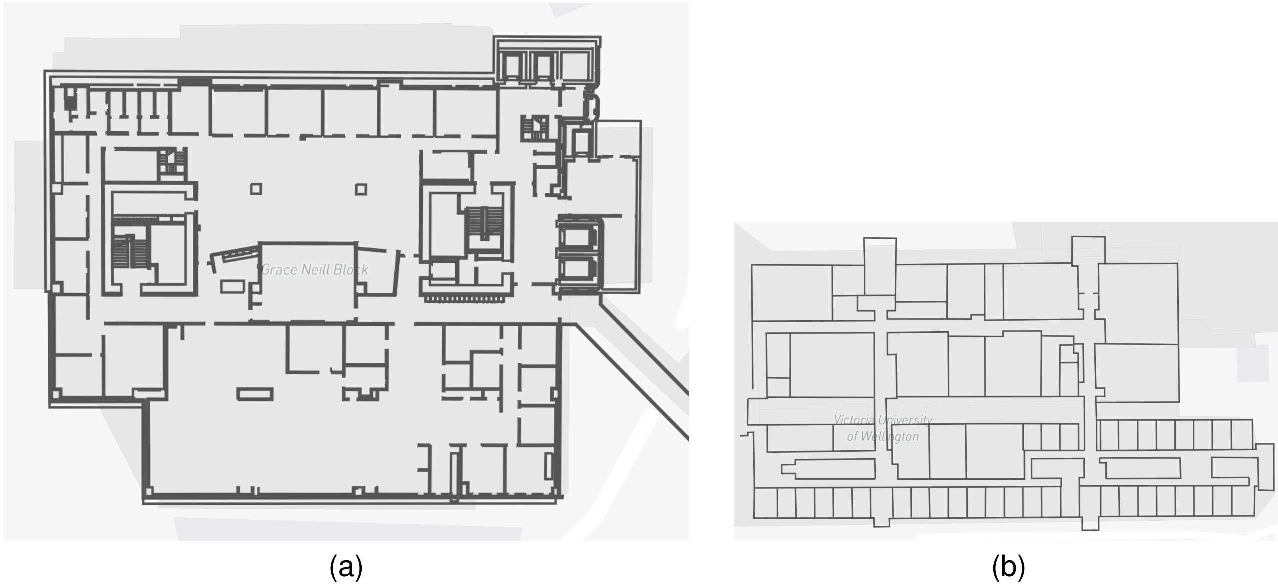

Fig. 6. Converted GeoJSON maps. (a) Wellington Regional Hospital - Grace Neill Block Level 3. (b) VUW - Cotton Level 2.

initial steps involved the removal of elements that could potentially clutter the layout, such as room names, using AutoCAD. Additionally, it was necessary to convert lightweight-polyline, arc, and point layers into polylines. This conversion was necessary for the DXF to GeoJSON tool to function properly as these specific layer types are not natively supported [28]. The conversion of hospital maps was done before the decision was made to carry out testing at VUW, however, these converted maps will be beneficial for when the application is implemented at Wellington Regional Hospital. Conversion of the Cotton maps required a more manual process as the only maps that could be acquired were in a PDF format. The outlines of the buildings were manually traced using an open-source tool called Img2GeoJSON [29]. Examples of the converted GeoJSON maps are shown in Figure 6. These maps are stored locally on the device to reduce the number of external services the application relies on.

As mentioned in Section IV-A, the locations of the beacons are stored in the same GeoJSON file as the map itself. Beacon locations can be added using any GeoJSON mapping tool such as GeoJSON.io [30]. This platform allows for easy visualisation and editing of the beacon placement on the map. This is a simplified process compared to manually typing in the latitude and longitude. With the addition of new beacon locations, the GeoJSON file would then be reimported into the application and the new beacon locations are loaded. This process is not ideal as it requires changing internal application files, however, it is a working solution until Kontakt implements a way to store beacon locations in the Kontakt Cloud.

C. Routes

Mapbox provides a directions API which determines the fastest route from a starting point to a destination. The result is provided in a JSON format that can be easily interpreted by the Mapbox Navigation SDK to display the turn-by-turn directions in the mobile application. However, this API is not designed for indoor routing since it only returns routes based on the nearest roads to the starting point and destination.

The application's core focus is to provide efficient turn-by-turn navigation, focussing on the location algorithm and displaying the turn-by-turn directions. Consequently, the decision was made to hardcode routes into a JSON file. This decision was based on prioritising a seamless user experience over the complexities of dynamically calculating routes for an indoor environment. This approach has its limitations since it is not scalable and there is no assurance that the JSON format that the Navigation SDK requires for routes will remain consistent. Therefore, a pathfinding algorithm that outputs the result in this format may be redundant in an upcoming release of the Navigation SDK. In light of this uncertainty and due to time constraints, the choice was made to not implement a pathfinding algorithm such as A* search. Opting for hardcoded routes allowed prioritisation of the location algorithm and turn-by-turn directions.

As mentioned earlier, the decision to test the application at VUW was to focus on the development by minimising the time spent on frequent trips between Wellington Regional Hospital and VUW for implementing application changes. The route implemented spans from the northwest entrance of Cotton Level 2, to the ECS office on Cotton Level 3. This route was chosen to best mimic a route at Wellington Hospital as it consists of intersections, elevators, and multiple levels. Figure 7 illustrates the Cotton Level 3 portion of the route. Focusing on one specific route ensured that sufficient time was dedicated to the development of the turn-by-turn directions, allowing for careful consideration and attention to detail.

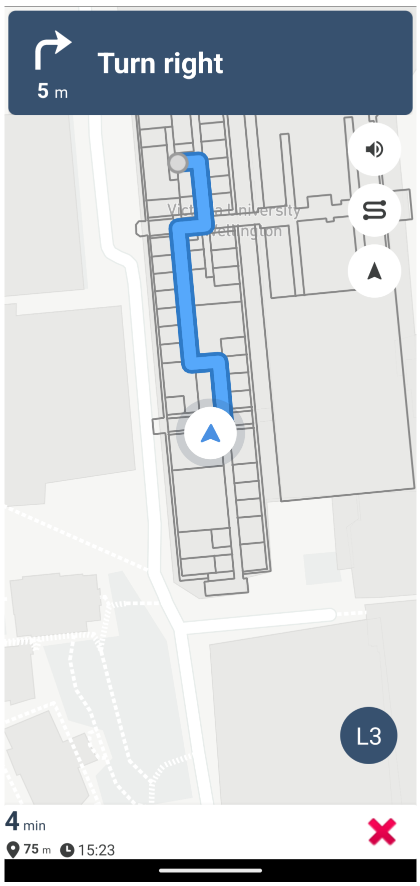

Fig. 7. Screenshot of the Cotton Level 3 Route Segment

The ability to dynamically switch levels based on user location and floor is a key aspect of indoor navigation, especially in multi-storey buildings like Wellington Regional Hospital and VUW. Given the complexity of these environments, it is important that the application provides an automatic way to transition between levels during navigation. The route from Level 2 Cotton to the ECS office is split up into a route for each level. As the user approaches the end of the Level 2 segment — defined by a distance of less than 2 metres — the application activates the Level 3 navigation segment, ensuring uninterrupted guidance. However, this does not always work seamlessly. Unfortunately, the application has memory leak issues associated with the switch between route segments which causes the application to crash periodically. This was investigated and it was found that the issue is caused by a bug in the Mapbox Navigation SDK which currently does not have a fix [31].

D. *Turn-by-Turn Navigation*

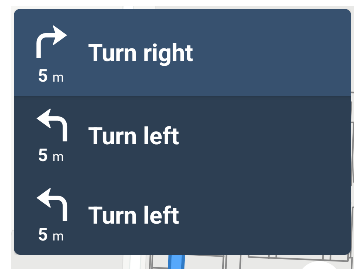

Fig. 8. Screenshot of the Turn-by-Turn Directions

Turn-by-turn instructions are integral to the application's navigation functionality for both visually impaired and non-impaired users. These instructions are stored in the JSON file of the route which enables the Mapbox Navigation SDK to retrieve them. Instructions are triggered depending on the device's proximity to specific manoeuvres, such as an upcoming turn or intersection. A visual representation of these instructions is displayed on the application interface within the manoeuvre view located at the top of the screen, as shown in Figure 7. To enhance usability, a tap on the manoeuvre view displays the upcoming manoeuvres, providing users with an overview of their journey, as illustrated in Figure 8.

In addition to visual instructions, voice prompts have been integrated using the Mapbox SDK, as this is an important aspect for visually impaired users. These audio instructions, directly retrieved from the route JSON, add an additional layer of guidance which improves the application's accessibility and inclusivity.

E. *Indoor Positioning Algorithm*

Utilising the known positions of a minimum of three beacons and the distances computed by the Kontakt SDK, a trilateration-based algorithm was used to estimate the user's real-time indoor position. The imprecision present in the distance measurements between the device and the beacons means that the algorithm is not able to pinpoint an exact location, but rather, offers a circle of where the user might be. To enhance the reliability of the user's estimated position, the centroid of this circle is selected as the probable location of the mobile device. A critical insight gained during development was that increasing the density of beacon deployment substantially constricts the potential region, thereby increasing the positioning accuracy.

PDR was then implemented. To begin with, it is important to define the concept of bearing in the context of navigation. Bearing refers to the direction or path along which something moves. In the context of PDR, a bearing listener was developed, deriving data from both the accelerometer and the magnetometer of the mobile device. The data from these sensors are responsible for determining the direction in which the user is moving.

Additionally, Android has an integrated step sensor, which is another key sensor in the PDR algorithm. A dedicated listener is set to this step sensor to update the user's location whenever a step is detected and the user's device detects less than three beacons. The location update, based on the detected steps, leverages the previously determined bearing to estimate the new location.

A critical component in refining the accuracy of the user's estimated indoor position is the integration of a location-snapping mechanism, similar to the strategy used by popular platforms like Google Maps [32]. Conventionally, this is done to ensure that the user's location is aligned with the nearest road and not in the middle of a field. Similarly, in the context of indoor navigation, the underlying principle of this algorithm ensures that the user's estimated position aligns with the designated route, mitigating scenarios where the position appears to be within structural obstacles like walls. When the user is navigating a route, this location-snapping mechanism is used to snap to the nearest point along the route.

Location snapping involves determining the closest point on the designated indoor route relative to the user's current estimated position. For each segment between two successive points on the route, the closest point to the user's location is calculated. This is done by projecting the user's position onto each line segment and determining the proximity to the user's actual position. The closest of these projected points across all segments of the route is then identified as the snapped location. Once this nearest point is identified, it's used to generate a new location object, preserving the bearing and altitude from the original user's location. This snapped location offers a more route-aligned representation of the user's position, ensuring that the displayed position remains logical and coherent within the indoor environment.

F. Features for Visually Impaired Users

Overall, the implementation of a new positioning algorithm has enabled the addition of accurate turn-by-turn directions. These directions are offered both visually and through audio prompts to enable greater accessibility to visually impaired users. The pre-existing speech-to-text feature has remained unchanged to convert the user's speech to text to start navigation to a point of interest. As only one route was implemented, the only supported speech is "ECS Office". However, this can easily be extended once more locations and routes are added.

Additionally, during the previous year's project, the user interface underwent extensive user testing for visually impaired users. The user interface has largely remained unchanged to ensure that the application remains accessible.

V. Evaluation

The evaluation section is a critical component of the project, aimed at assessing the effectiveness, usability, and accuracy of the proposed application. Specific evaluation points include navigation speed, usability, and the accuracy of location updates.

A. Navigation Speed

Careful consideration has been taken regarding the method of user evaluation for the mobile application. This evaluation is focused on the time it takes participants to navigate from the northwest entrance of Cotton Level 2 to the ECS office on Cotton Level 3.

There were six visually impaired participants in total - three that used the proposed application, and three that did not. This enables an evaluation of the application's impact on navigation speed compared to the non-application group. Selecting individuals who are unfamiliar with the Cotton building at VUW minimises the potential influence of prior knowledge or experiences on the results. This allows for a more objective assessment of the application's performance and effectiveness in facilitating navigation for users who may be new to the hospital environment. A substantial amount of time has been spent working on an ethics application for VUW Human Ethics Committee (HEC) approval in order to carry out this evaluation. The application has been approved by the HEC with the ID 0000031059. Additional ethics approval from CCHV has been given, solidifying the project's compliance with ethical guidelines [5].

The visually impaired participants all had a glasses prescription between -2 and -4.5. This corresponds to being short-sighted. Individuals who are short-sighted have clear close vision but distance vision is blurry. This is an important group of visually impaired users to evaluate the application as these users may encounter difficulty distinguishing signage in the hospital environment unless they are in close proximity. The usability of the application for individuals with other visual impairments such as sensitivity to light (Irlen Syndrome) was not considered as the previous project did extensive user testing and these types of visual impairments were considered in the original application design [5]. However, it would have been beneficial to test the application for these types of visual impairments for the newly developed map.

All participants started at the northwest entrance of Cotton Level 2 and were instructed to make their way to the ECS office on Level 3. A paper map of the Cotton building was displayed at the starting point for the group not using the application. These maps displayed an icon indicating where they are and where the destination is. This was done to emulate the conditions present at Wellington Regional Hospital, where entrance maps are available to assist visitors in navigating the premises. Participants were instructed to refrain from seeking directions from anyone during the navigation. This was done to minimise the results being influenced by external factors.

The time taken for each participant to reach the ECS office was recorded in Table II. The participants who took part in the evaluation are anonymised as per their requests, therefore, references to the participants have been replaced with numbers.

TABLE II
USER TESTING NAVIGATION TIMES

Participant	Using Application	Time (Minutes:Seconds)
1	Yes	1:56
2	Yes	2:02
3	Yes	2:26
4	No	4:16
5	No	4:18
6	No	4:08

Table II shows that participants that used the application were able to navigate to the final destination faster than those with only a paper map. The average time of participants with the application was 2:08, while the average time of participants with only a paper map was 4:14. This evaluation shows the application can reduce navigation time by up to 50%.

B. Usability

Further user feedback was sought regarding improvements to the user interface. During the time of user testing, the application had level selection buttons that could switch between the levels of the map. Two participants mentioned that these buttons were confusing because you could switch to level 2 when currently on the level 3 segment of the route. This resulted in the route being

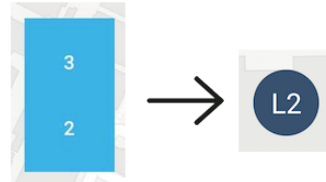

Fig. 9. Level Selector Compared to Level Icon

displayed on the incorrect map which caused confusion to some participants. This feedback was taken on board and replaced with a level icon instead of a level selector, as seen in Figure 9. The level icon automatically switches to 'L3' when the the route progresses to the level 3 segment of the route.

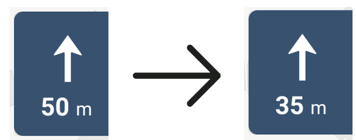

Fig. 10. 50m Increment Compared to 5m Increment

Another change based on user feedback was to the manoeuvre view which displays the turn-by-turn directions. The application initially displayed the distance remaining in increments of 50 metres. User testing found that this made it difficult for participants to determine how far they had until they should take the next manoeuvre. Subsequently, this increment was changed to 5 metres to provide more accurate distance estimations. This change is shown in Figure 10.

C. Accuracy of Location Updates

TABLE III
COMPARISON OF LOCATION TRACKING METHODS (AVERAGED)

Method	Area Per Beacon	Error	Update Interval
Trilateration	$2.9\,m^2$	1.49m	3.39s
Trilateration	$5.4\,m^2$	4.46m	7.35s
Trilateration + PDR	$5.4\,m^2$	1.33m	0.91s

Table III presents a comparison of the location tracking methods using BLE beacons, with the route specified in Section IV-C. Each methodology underwent testing in 5 predefined locations, 10 times each, and the resulting positional error was averaged. The assessment was carried out by standing in the 5 predefined locations along the route and then contrasting these with the positions deduced by the algorithm. The time between updates was measured differently as measuring it while stationary would not accurately show the improvements of PDR. Instead, the time between updates was measured while walking at a constant speed and measuring the time between updates.

Initially, to maximise the accuracy in positioning, a dense deployment of 56 beacons was chosen for the Cotton route. Given that the route to the ECS office is approximately $162.5\,\mathrm{m}^2$, this translates to a beacon density of approximately one every $2.9\,\mathrm{m}^2$. While this high-density approach produced a remarkably low average positional error of 1.49m, the volume of beacons deployed makes it an impractical and non-scalable solution. For perspective, adopting such a strategy for the Main Block Level 2 of Wellington Regional Hospital, spanning an area of $14\,733\,\mathrm{m}^2$, would require the deployment of 5,081 beacons for just a single level of one building.

Recognising the inefficiencies and lack of sustainability of such an intensive beacon deployment, an alternative strategy was tested using only 30 beacons, resulting in one beacon every $5.4\,\mathrm{m}^2$. As anticipated, this reduction produced a higher update interval (7.35s) and positioning accuracy (4.46m).

To enhance this performance, PDR was incorporated alongside trilateration. As outlined in Section II, PDR was implemented as it has been shown to improve the accuracy of indoor positioning algorithms [15].

As seen in Table III, the testing revealed that merging trilateration with PDR, even with a reduced coverage of one beacon per $5.4\,\mathrm{m}^2$, produced performance metrics similar to a trilateration method with a coverage of one beacon per $2.9\,\mathrm{m}^2$. Specifically, the application maintained an average positioning error of 1.33 metres and an update every 0.91 seconds. Therefore the combination of trilateration with PDR was chosen not only for its technical merits but also for its balance between accuracy and resource efficiency in an indoor setting.

Ordinary trilateration with a low density ($5.4\,\mathrm{m}^2$) produces a much higher error than both trilateration with a high density ($2.9\,\mathrm{m}^2$) and trilateration with PDR. This is expected as when fewer beacons are used, more dead spots are introduced where there are not enough beacons to perform trilateration. Therefore, the algorithm would think the device is still in the old location because it can not detect at least three beacons for a location update. The dead reckoning algorithm fills these dead spots to predict the device's location, which ensures regular location updates regardless of beacon dead spots.

This evaluation shows that the proposed location tracking method of trilateration and PDR achieves an average accuracy of 1.33 metres. This accuracy aligns with existing solutions, which typically achieve accuracies of less than 4 metres [1], [2].

VI. Conclusions and Future Work

A. Conclusions

In this project, a comprehensive exploration of an indoor wayfinding application designed for use in Wellington Regional Hospital has been presented, using a hybrid approach that combines BLE beacons for trilateration and pedestrian dead reckoning for enhanced localisation. The research undertaken serves as a crucial step towards improving indoor navigation applications, particularly in the context of healthcare institutions where effective and efficient wayfinding is particularly important.

The application provides accurate location updates and turn-by-turn directions both visually and spoken. The application has been evaluated by visually impaired users and has been shown to reduce navigation time by up to 50% compared to using printed maps. The application has also been evaluated for accuracy and has been shown to achieve an average accuracy of 1.33 metres.

The developed application serves as an adaptable system that can be implemented in various indoor environments, not limited to healthcare settings. User tests confirmed the application's ease of use and functionality, indicative of its readiness for broader testing and subsequent deployment at Wellington Regional Hospital.

B. Future Work

Although evaluation showed promising results, a true test of the application's performance would be to implement it in Wellington Regional Hospital. This would allow for a more realistic evaluation of the application's performance in a real-world environment. Hospital maps have already been created for Wellington Regional Hospital, therefore, this would simplify the process of integrating the application into the hospital. Beacon locations would have to be recorded and added to the application. Further thought may have to be taken in to consideration for the differences in the hospital environment compared to VUW. For example, the hospital has much larger open spaces and corridors than the VUW Cotton route. This will likely require fine-tuning the location algorithm to account for this.

A key step in making this application ready for deployment is the dynamic generation of indoor routes. The developed application uses hardcoded routes which is not a scalable solution. Due to there not being a current affordable indoor route generation service, this would require implementing a dedicated route generation algorithm such as A* search. This would be a time-consuming process, however, it would allow for dynamic start and endpoints to be selected by users.

Another improvement for the application would be to further investigate the memory leak issue with the Mapbox Navigation SDK as mentioned in Section IV-C. This would allow for the application to be more robust and reliable. This would also allow for the application to be tested in a more realistic environment without the risk of the application crashing.

As it stands, the application is not connected to the CCHV patient appointments database. Future work would also see integration of the CCHV database which would allow users to see their appointment details. The architecture of the application is designed to accommodate this integration in the future.

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