A Smart Marker-based Indoor Navigation System

BY

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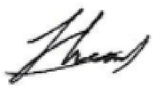

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ABSTRACT

Blind people have difficulties in navigating indoor spaces, which may lead to accidents, inefficiency, and frustration. Normal individuals also face challenges in complex or unfamiliar indoor environments. This paper studies and compares the advantages and disadvantages of indoor navigation methods. We found that traditional navigation methods like GPS and Bluetooth beacons have limitations in terms of accuracy and user experience. Therefore, this project proposes a smart marker-based indoor navigation system to overcome these issues. The proposed system uses smartphone cameras for real-time marker recognition, and audio instructions for user support. The proposed system can create a map for a target indoor location, and the map data will be utilized for navigation and localization. The proposed system also employs algorithms to calculate the shortest path for navigation and estimate the user position for localization when the user scans a marker. The project aims to provide a low-cost, accurate, and real-time indoor navigation system and bridge the gap between traditional methods' limitations and user needs.

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LIST OF ABBREVIATIONS

AR	Augmented Reality
QR	Quick Response
ViNT	Visual Navigation Transformer
CNN	Convolution Neural Network
SDK	Software Development Kit
BLE	Bluetooth Low Energy
GPS	Global Positioning System
CAD	Computer-Aided Design
RSSI	Received Signal Strength Indicator
MAC	Media Access Control
ORB	Oriented FAST and rotated BRIEF
SURF	Speeded-Up Robust Features
GW-KNN	Gaussian Weighted K-Nearest Neighbor
KNN	K-Nearest Neighbor
IMU	Inertial Measurement Unit
PDR	Pedestrian Dead Reckoning
ANN	Artificial Neural Network
SVM	Support Vector Machine
RMS	Root Mean Square
RAM	Random-access memory
FFI	Foreign Function Interface

Chapter 1

Project Background

In this chapter, we present the background and motivation of our research, our contributions to the field, the outline of the thesis, and the problems we need to solve by doing this project.

1.1 Introduction

Indoor navigation technology has developed rapidly because this field has become the focus of researchers in the past decade. The application can be used in human assistance for blind people or the elderly, robot navigation, and tourist guidance [7]. Blindness is a major challenge, which affects all aspects of personal life, especially the ability to perceive and interact with the real world. According to literature [8] 2020 statistics, China and India together account for 49% of the total burden of blindness in the world, because both countries have the largest populations. Besides that, Nepal has the highest overall rate of vision impairment, and South Sudan has the highest rate of blindness.

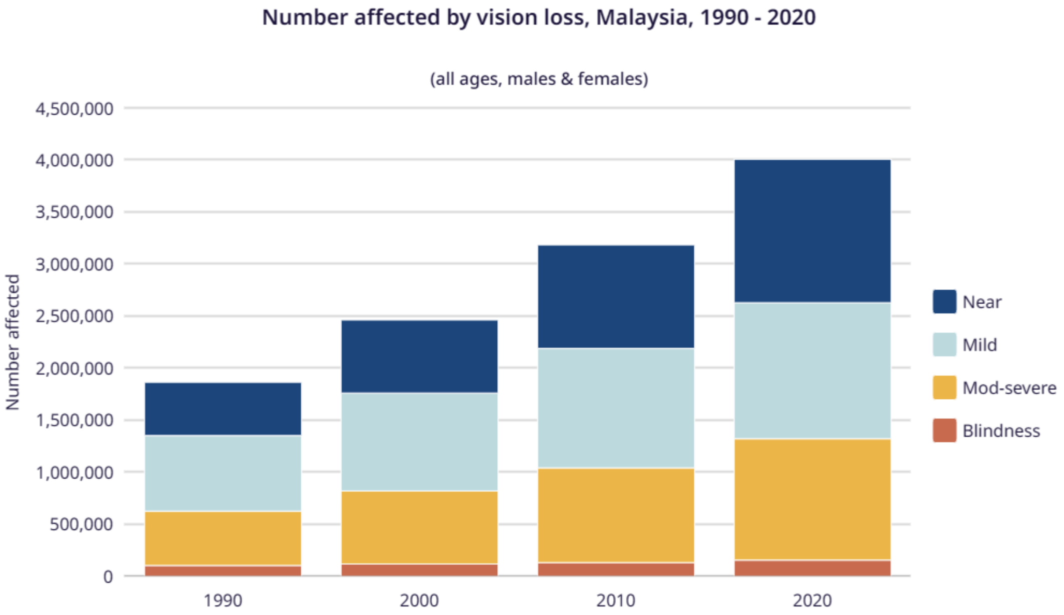


Figure 1.1 The number affected by vision loss in Malaysia between 1990 and 2020 [8]

In 2020 in Malaysia, it is estimated that there are 4 million visually impaired people, including 160,000 blind people. As shown in Figure 1, the number of people affected by vision loss in Malaysia increased between 1990 and 2020, including all ages and genders. People with loss of sight have difficulties accomplishing daily tasks independently, such as driving, reading, and basic mobility. Besides that, people with loss of sight have a higher risk of accidents and injuries both indoors and outdoors. This includes falls, collisions, and accidents while navigating in the environment. Therefore, blind people need assistance devices that are low-cost, user-friendly, and accurate [7].

Indoor navigation has become more important for several reasons since it addresses the challenges of navigating and interacting within indoor spaces. Indoor navigation helps users find specific locations and services within complex indoor environments such as shopping malls, airports, hospitals, convention centers, museums, and large office buildings. Indoor navigation application also enhances the overall user experience within indoor spaces by providing convenience and reducing frustration when facing complex or unfamiliar indoor spaces. Indoor navigation applications can improve efficiency and save time for individuals to reach their destination. Indoor navigation is crucial for individuals with disabilities. Especially blind people, it assists them to navigate public indoor spaces independently.

Furthermore, indoor navigation is more challenging than outdoor navigation. Global Positioning System (GPS) is suitable for outdoor navigation, but not suitable for indoor navigation. This is because the signal in the indoor environment is weak compared with the outdoor environment. [9]. Most indoor navigation methods find it difficult to adapt to the changes of an indoor environment. In addition, the accuracy of vision-based indoor navigation methods can be affected by the light condition of the indoor environment and occlusion [7].

There are three major categories found in indoor navigation, including vision-based methods, communication-based methods, and dead reckoning-based methods. Vision- based methods utilize video cameras to act as human eyes for tracking or retrieving visual information. In dead reckoning technology, it uses different types of sensors, such as accelerometers, compasses, gyroscopes, and magnetometers, but over time, it is easy to make errors. In wireless technology, the method relies on signals from Wi-Fi or Bluetooth beacons, which may not be available or reliable in all indoor environments. Signal interference, limited coverage, and hardware compatibility issues can affect the accuracy. Communication-based methods involve wireless technology like near-field communication (NFC), radio frequency identification (RFID), Bluetooth Low Energy (BLE) beacons, and Wi-Fi [7].

Vision-based methods have become an interesting topic for researchers because of their accuracy, ease of use and installation, low power consumption, and low cost. Besides that, vision-based methods can assist people with loss of sight by using a camera to replace the human eye. Therefore, computer vision is a good choice for indoor navigation. Vision-based methods can be split into two different categories, which are markerless-based methods and marker-based methods. Marker-based methods involve printed markers and they can be recognized with a camera. Markerless-based methods identify the user's location by using natural landmark tracking without any printed markers [7].

1.2 Problem Statement

Traditional navigation methods like Bluetooth beacons are expensive compared to fiducial markers, require high maintenance, and struggle with battery life issues [7]. Most traditional navigation systems have difficulties in adapting to the environment, which means that the system has pre-built a map for a specific location. This will cause a lack of flexibility on environmental changes. Moreover, users will feel anxious when faced with unfamiliar indoor spaces or getting lost, especially blind people. While traditional navigation methods like GPS provide a low-accurate localization result. Besides that, users may take a long time and distance to reach their destination. Plus, unclear and non-real-time indoor guidance is one of the issues in traditional navigation methods. This leads to users' inefficiency and waste of time and makes users feel stressed and anxious, particularly in crowded or unfamiliar environments [10]. Especially in a space like a shopping mall, users may have a negative user experience of the location, so the number of visitors will decrease. Furthermore, blind people may face challenges in comprehending their surroundings and navigating indoor spaces independently, especially in crowded environments. Besides that, some indoor navigation devices for blind people can be inconvenient, as they may require complicated setup procedures and specialized and expensive hardware.

1.3 Project Scope

A smartphone marker-based indoor navigation system designed to assist blind people in navigating unfamiliar indoor environments more effectively. Besides that, traditional navigation methods like GPS might not be accurate. Thus, a novel solution is proposed that utilizes a combination of fiducial markers placed within an indoor environment, and a mobile application that accesses audio, compass, and camera.

The application allows the user to capture these markers using a smartphone camera to recognize their location. The application allows users to choose a destination and calculates the shortest path to the destination. The application can access the mobile compass to guide the user moving the right direction. Besides the compass, the application can provide real-time audio instructions to guide blind people through the environment. Users can get an interactive and engaging experience and get a clear direction according to compass, vibration, and audio information.

In short, the innovation of this project lies in its integration of fiducial markers and smartphone technology to provide an accurate and efficient indoor navigation system. By leveraging audio and compass, the system offers real- time and clear guidance and improves the independence and safety of blind people in unfamiliar indoor environments.

1.4 Project Objectives

The main objective of this project is to develop a smartphone-based indoor navigation system due to the popularity of smartphones and their capabilities. The systems leverage the smartphone camera and other technologies to provide navigation. A smartphone-based solution can provide audio instructions to assist blind people.

The sub-objectives of the project are as follows:

- The system provides a user-friendly interface for administrators to create and manage floor graphs. It enables them to generate different floor graphs, generate different markers, define the marker placement and the connection between markers, and insert relevant information to each marker.
- The system provides accurate and real-time user positioning for effective indoor navigation. It can determine a user's location within an indoor space when they detect fiducial markers like ArUco markers.
- The system generates the shortest routes and provides clear, user-friendly instructions to guide users from their current location to their destination within the indoor environment. Compass and vibration will be implemented to guide the user to move in the correct direction. In addition, audio instruction also will be provided to assist the user, particularly blind people.

1.5 Contributions

The application tailored for blind people will enhance accessibility, and enable them to navigate indoor spaces confidently and independently. The application has made great contributions to enhancing indoor pathfinding and user experience by providing the shortest route and clear instructions to users. The application meets the needs of new visitors and tourists by providing clear and intuitive guidance in complex environments, such as shopping malls and airports. This will improve visitor experiences, and increase the satisfaction and economic opportunities for businesses in that location. By considering factors such as cost-effectiveness and energy efficiency, this project has solved practical problems in implementing indoor navigation solutions to ensure their long-term feasibility. Besides cost-effectiveness and energy efficiency, this project aims to apply an approach that is easy to implement and suitable for any indoor environment.

Chapter 2
Literature Review

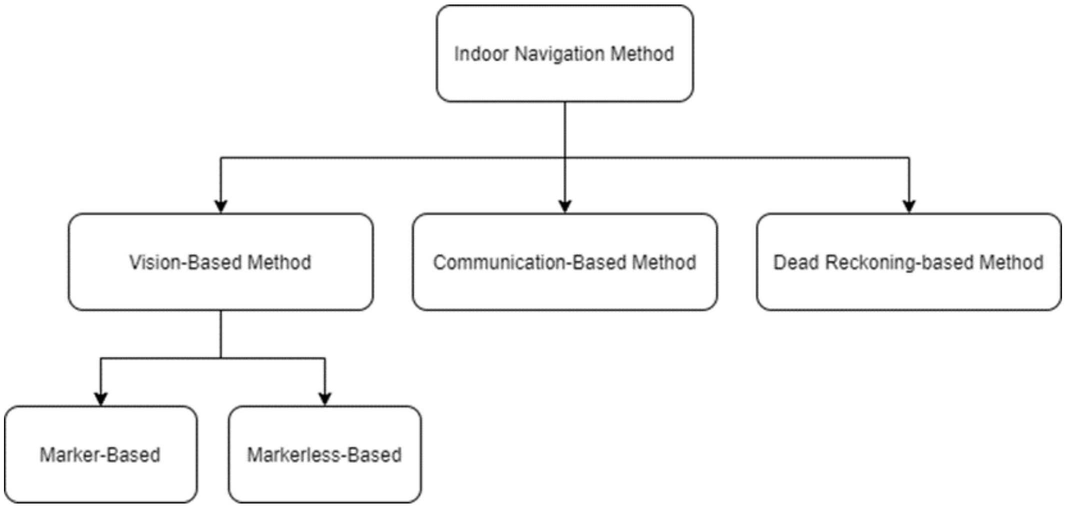


Figure 2.1 A tree diagram for the indoor navigation method

As shown in Figure 2.1, this chapter will introduce several existing indoor navigation methods, including the vision-based method, communication-based method, and dead reckoning-based method. The vision-based method can be split into two different categories, which are marker-based and markerless-based. Lastly, we will also study and compare the advantages and disadvantages of each indoor navigation method.

2.1 Vision-Based Method

This section will introduce two types of vision-based methods, which are marker-based methods and markerless-based methods. The marker-based method creates explicit markers that can be captured using the smartphone camera to get navigational guidance. Markerless-based methods detect visual landmarks in the scene environment to identify the user's location and perform navigation based on the user's location.

2.1.1 Marker Based Method

There are two types of marker-based methods reviewed, which are AR (Augmented Reality) marker-based and QR code-based. Both marker-based methods are taken to review since they have their interesting part. AR markers can impose virtual information on the real environment, while QR codes can be easily decoded.

2.1.1.1 AR Marker

AR marker-based indoor navigation is a low-cost, easy-to-deploy, and extendable method. It uses AR markers and places them on the ceiling, wall, or floor of the building. AR markers can be detected by smartphone cameras for virtual overlay to provide clear guidance to users. In addition, various kinds of AR marker toolkits are available online, such as ARTag, ARToolKit as shown in Figure 2.2, AruCo, and ARToolKitPlus.

Figure 2.2 Example of ARToolKit [4]

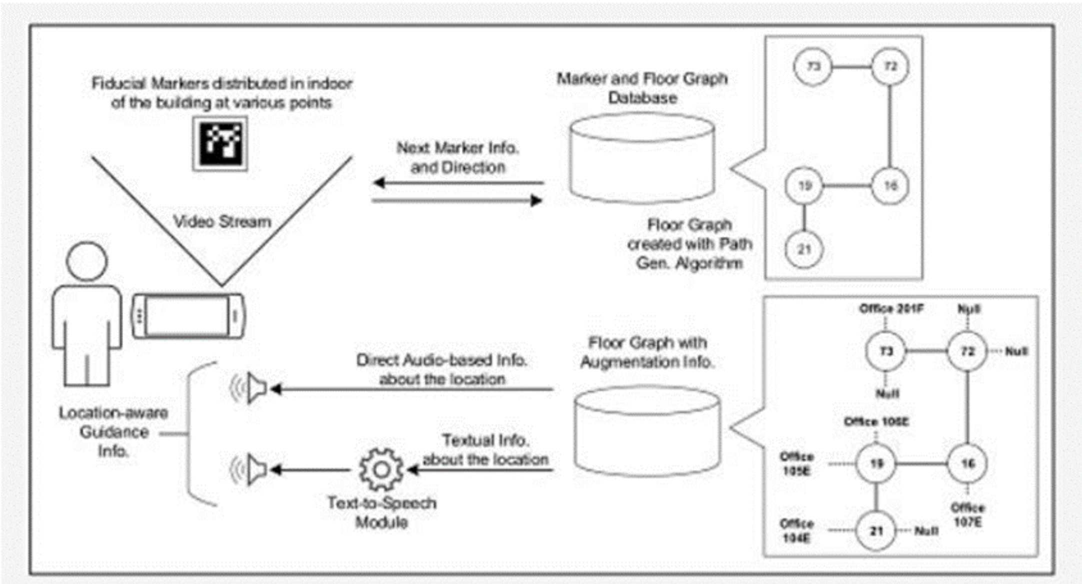


Figure 2.3 Block diagram of the AR marker-based indoor navigation system [4]

Figure 2.3 shows the system proposed in the literature [4] which uses a smartphone camera to scan the markers to receive the guidance information from the marker and floor graph database in auditory form. This database contains floor graphs that represent the layout and connectivity of different marker nodes placed in the building. In addition, the floor graph is augmented with textual information. Based on the floor graph, the shortest path is generated using Dijkstra’s algorithm. The system will provide audio and textual guidance to the user. The audio guidance is converted from text information stored in the database by using a text-to-speech module.

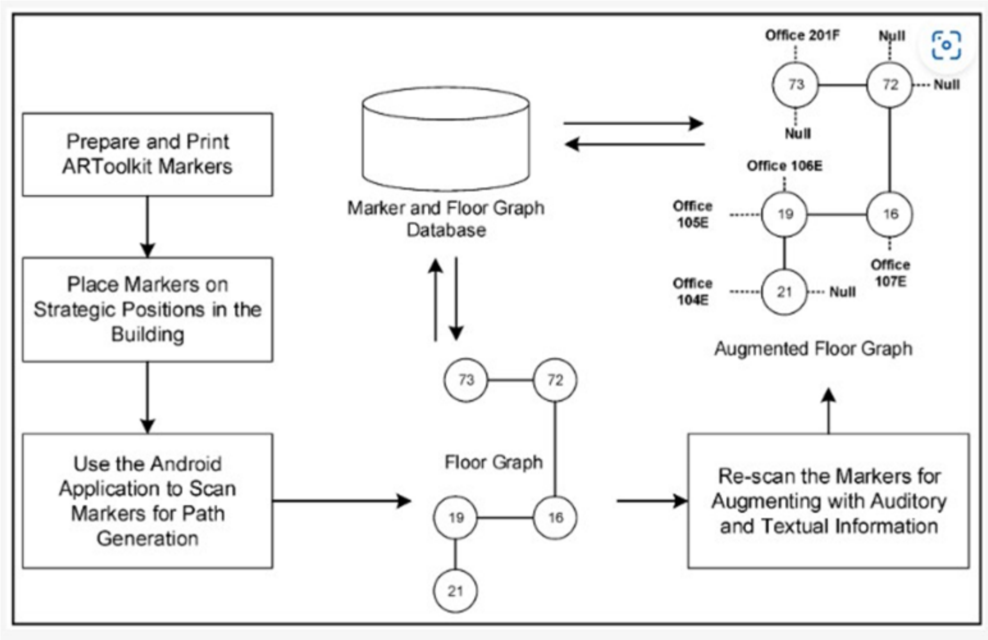


Figure 2.4 Floor graph generation [4]

For the floor graph generation as shown in Figure 2.4, the markers are printed and placed in the building. Then, the administrator will scan all markers to connect all the markers installed and generate a floor graph which will be stored in the database. For the augmentation process, all the markers will be re-scanned to add the auditory and textual information into each marker and stored in the database.

This approach is flexible. It can install new markers, remove markers, and modify the floor graph anytime. Thus, it can accommodate the changes in the indoor environment. The approach is applicable for binders, tourists, and new visitors. Besides that, this approach applies to any building. In addition, it is a cost-effective method since it only requires printing the markers and low deployment cost compared with other methods.

However, a low illumination environment will lead to the failure of mark detection. To solve this problem, the flashlight of the smartphone will automatically turn on in a low-illumination environment. Besides that, it is difficult to navigate in the environment when the user needs to maintain the smartphone orientation. Furthermore, it is required to place the marks correctly, and the use of the marks may affect the beauty of the building. Hidden markers or natural landmark tracking could be the solution to solve this issue.

2.1.1.2 QR Code

QR-based indoor navigation recognizes the QR code to identify the user's location. The QR codes are placed in the indoor space, and each QR code has a unique ID that is used to retrieve the encoded information. Literature [1] proposed a QR navigation system called QRNav system as shown in Figure 2.5.

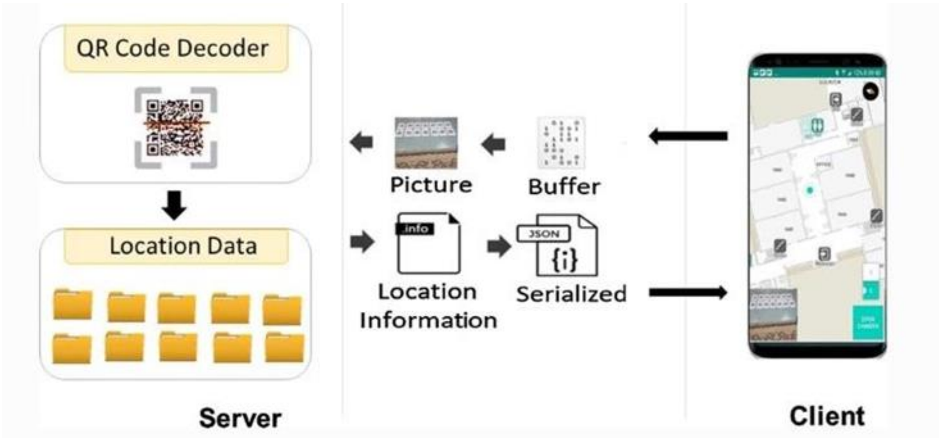


Figure 2.5 Overview of the QRNav system [1]

The client uses the smartphone camera to capture the image when walking, and then the image will be sent to the server to perform QR code detection. Then, the unique ID of the detected QR code will be extracted using a decoding method. According to the unique ID, the server looks up the location data and sends the serialized location information back to the client.

QR-based indoor navigation approach provides accurate navigation services. Besides that, the decoding process does not require powerful devices. Furthermore, this approach can identify static obstacles in the navigation path, but it requires attaching the QR codes to walls and doors. Moreover, locations with similar appearance are not an issue for the QR code-based method.

However, users are required to maintain the smartphone in a fixed position for a long time. Moreover, QR code placement will affect the beauty of the building. In addition, the walking speed of the user will affect the performance of this approach because it will capture blurry pictures when the user is walking at a high speed. Compared with BLE based system, this approach consumes more time due to client-server communication.

2.1.2 Markerless-Based Method

There are two markerless-based methods reviewed, which are CNN-based recognition and Visual Navigation Transformer. CNN-based recognition is a deep learning model to identify user position by capturing the images of the user environment. Visual Navigation Transformer is a foundation model that allows people to solve specific machine learning problems using much smaller datasets.

2.1.2.1 Convolution Neural Network (CNN) Based Indoor Scene Recognition

Literature [1] proposed a vision-based navigation system called the CamNav system as shown in Figure 5. A trained deep-learning model is applied to recognize the location from captured images.

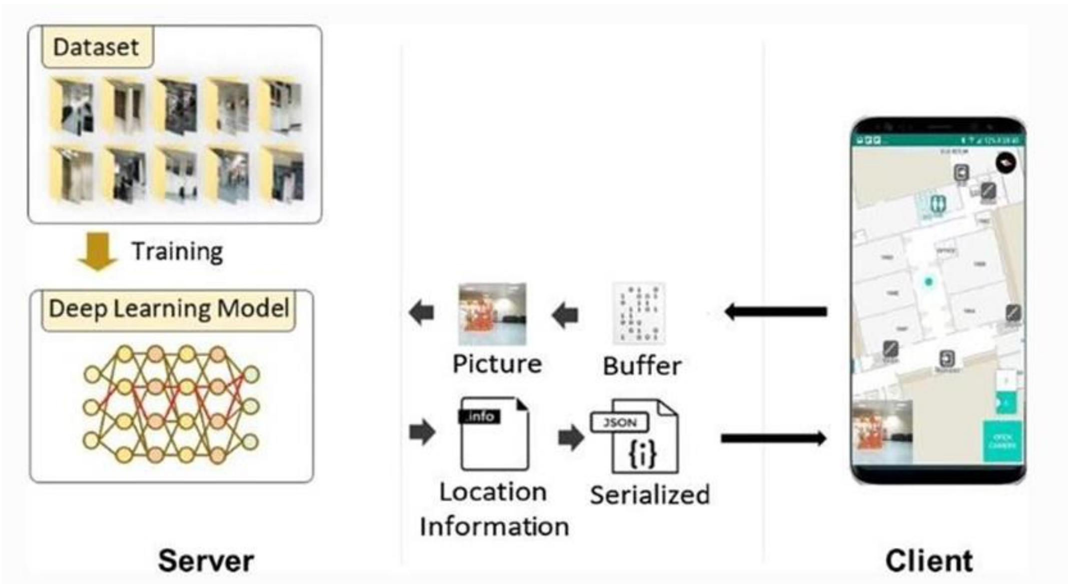


Figure 2.6 Overview of the CamNav system [1]

Based on Figure 2.6, the client uses the smartphone camera to capture different images of different landmarks for positioning purposes, and then the image will be sent to the server to be stored in the dataset. The server processes the content of the images and identifies the user location from the images using a trained deep-learning model. Then, the client will receive the location information from the server.

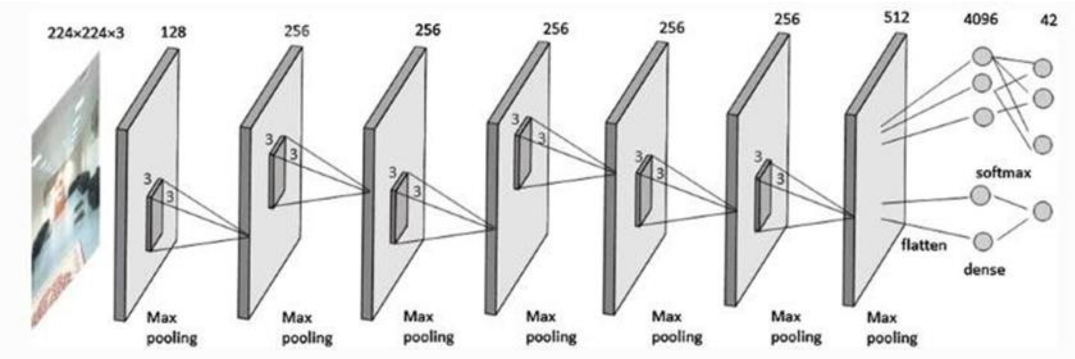


Figure 2.7 The architecture of the developed deep-learning model [1]

Based on Figure 2.7, The deep learning model implemented in the server is built using TensorFlow. This model consists of convolutional layers, pooling layers, and fully connected layers at the end. The convolution layer calculates the output of neurons associated with each local region of the input. Convolutional layers can operate on raw input or output from preceding convolutional layers. Convolutional layers apply filters to detect features in the RGB image or the previous layer's feature map, and then generate a new feature map. Each convolutional layer has a max pooling layer to reduce the resolution of the resulting feature map by performing down sampling. The reduction helps the model to achieve translation invariance, reduce the amount of calculation, and reduce the number of parameters. In the end, the feature map is flattened into vectors and fed into a fully connected layer to build a model. The output of a fully connected layer is normalized by the SoftMax function. The SoftMax function can generate an output representation based on probability distribution.

The indoor map and CAD drawings of indoor areas are applied to create the navigation module. The navigation module uses JSON arrays to hold routing and navigation information. Each JSON array is focused on a specific route and contains instructions for that route, which were created manually. The instruction provides commands (left, right, straight), the distance between the current location of the user and the destination, and critical locations like junctions or lifts.

This approach is more accurate and reliable compared to the BLE approach. Besides that, this approach can identify static obstacles in the navigation path because it is trained to recognize them.

However, this approach consumes more time due to client-server communication. In addition, the walking speed of the user also will affect the performance. Furthermore, it is difficult for users to keep the orientation of their smartphones for a long time for location recognition. Other than that, locations with similar appearances may cause this approach to fail.

2.1.2.2 Visual Navigation Transformer (ViNT)

Literature [5] proposed a foundation model called Vision Navigation Transformer (ViNT), and this will be introduced into vision-based robot navigation. ViNT adopts a transformer-based architecture to learn navigation enlightenment and effectively adapt to various downstream navigation tasks. ViNT is trained with a goal-reaching objective that can be used with any navigation dataset.

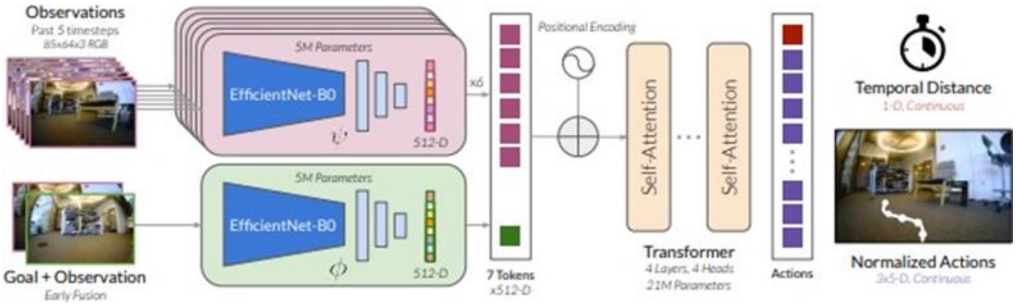


Figure 2.8 ViNT Model Architecture Diagram [5]

According to Figure 2.8, The robot is tasked to navigate to a subgoal specified by an image observation. ViNT takes current and past visual observations and a goal image as input. ViNT uses two EfficientNet encoders ψ, ϕ, to generate input tokens to a Transformer decoder. The ψ encoder tokenizes the past and current observation images and generates a flattened feature vector (observation tokens) from the final convolutional layer. When using an EfficientNet encoder to extract features from the goal image, the results were unsatisfactory, as the goal information was often ignored entirely. This is because the effective features for image-based goal-reaching tasks are usually relative, encoding the difference between the current observation and the goal, rather than solely depicting the goal itself. Thus, a separate goal fusion encoder, EfficientNet encoder ϕ, tokenizes the current observation and the goal image to obtain the flattened goal token. The observation and goal tokens are combined with a positional encoding and fed into a Transformer decoder. Then, the resulting sequence is combined and passed through a fully connected network to predict the number of time steps needed to reach the subgoal and a sequence of future actions leading toward the subgoal.

Since ViNT is a foundation model, it can be fine-tuned to solve particular tasks with minimal data because it has learned a lot about various topics from a wide range of sources. This model is capable of tackling large-scale navigation challenges when given long-range guidance without human intervention. This model also can be used for almost any mobile robot dataset. In addition, ViNT is capable of navigating new environments without prior exposure and controlling new robots without prior training or performing indoor mapping. Thus, it is an adaptive and efficient model compared to training a new model from scratch.

ViNT comes with a higher computational demand, which can be a problem for devices with limited power resources. ViNT is more expensive at deployment than simpler feedforward convolutional networks. Currently in literature [5], the model is trained for particular types of data and actions, which may limit its ability to adapt to different situations. To enhance its versatility, ViNT trained using a wider range of data types, and action possibilities, allowing it to perform well in various scenarios.

2.2 Communication-Based Methods

The communication-based method uses wireless technology like Wi-Fi and Bluetooth. There are two communication-based methods reviewed in this section, which are the BLE fingerprint and the Wi-Vi fingerprint. BLE fingerprint is the combination of Bluetooth signal, fingerprint positioning, and Bluetooth beacons. While Wi-Vi fingerprint is the combination of Wi-Fi, visual features, and fingerprint positioning.

2.2.1 BLE Fingerprint Positioning

According to the literature [2], RSSI (Received Signal Strength Indicator) based fingerprint positioning methods are more mature in the current indoor positioning system. This approach is applicable in complex and changeable environments. BLE fingerprint positioning is considered RSSI-based fingerprint positioning since the position of a device is determined based on the RSSI values of Bluetooth signals. BLE fingerprint positioning technology supports portable beacons powered by batteries. The two stages of fingerprint localization are:

Offline stage:

- Identify the measurement location area

- Install the Bluetooth Beacon in the area
- Record the location coordinates
- Divided the area into several grid spaces
- Fix the RSSI acquisition access point in each grid space
- Collect the Bluetooth signal of the user's location.

Online stage:

- Match the Bluetooth signal with the fingerprint database
- Obtain the location of the user

The advantages of using BLE technology are low cost, low power consumption, and fast connection. In addition, most mobile devices with Bluetooth can use this approach, so it is highly feasible. Fingerprint-matching positioning technology provides high positioning accuracy without obtaining the location of Bluetooth beacons or measuring time and angle. Thus, this approach combines both technologies will bring benefits like easy to implement, highly feasible, and low cost. Furthermore, this approach avoids the inherent error of ranging and effectively improves positioning accuracy. Otherwise, the scene's positioning accuracy can be affected by the location fingerprint database's capacity. However, the Bluetooth beacon has a short battery life, which will cause the battery to frequently change.

According to the literature [1], the BLE beacons-based navigation approach is unable to detect obstacles like doors or walls. Other than that, the position of the user is not estimated accurately compared with QR-based and CNN recognition-based. However, BLE beacon positioning can get the real-time position of the user effectively when navigating through straight paths. Moreover, the performance of BLE beacon positioning will not be affected by locations with similar appearance and the walking speed of the user.

2.2.2 Wi-Vi Fingerprint

Literature [3] proposes a combination of communication-based and vision-based methods called Wi-Vi fingerprint, which is the integration of Wi-Fi and visual features. The Wi-Fi features consist of MAC address and RSSI information. The sign features consist of ORB and SURF holistic features. The scene's visual features are represented by ORB local features. Literature [3] uses EXIT signs as sampling sites. The Wi-Fi signals and the visual features captured from the images of the EXIT sign site are distinct for one site.

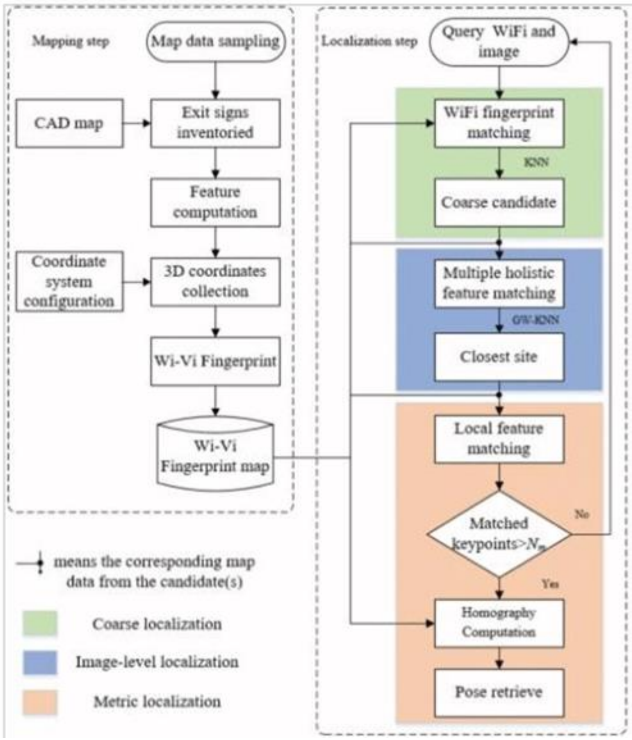


Figure 2.9 The block diagram of the proposed Wi-Vi fingerprints [3]

In the mapping step, the EXIT sign is used to map data sampling. Then, the data sampling is inventoried according to the position sequence in the computer-aided design (CAD) construction drawing. Then, Wi-Fi and image data are collected in every sampling site to improve localization robustness. Then, Wi-Fi and visual feature computation is performed:

- Wi-Fi feature computation: Apply a mean filter to extract stable Wi-Fi features which are MAC address and RSSI. Thus, it can save the RAM of smartphones and improve computational efficiency since not all sampling data is stored.
- Visual feature computation: A sign verification is applied to verify the visual features from a sign while a sampling site recognition is applied to recognize the visual features from the scene images. Then, ORB and SURF feature descriptors are applied to compute the sign holistic features and scene local features. The holistic features are for fast image matching to derive the closest image. The local features are for verification and homograph computing.

After feature computation, it uses the 3-D coordinates of the EXIT sign vertices to perform position calculation, but the complexity of the calculation is high. To solve this issue, the plane coordinate system of the EXIT sign is used for transition calculation. Then, the Wi-Fi and visual features are integrated to form a Wi-Vi fingerprint and the Wi-Vi fingerprint will be stored. Finally, the Wi-Vi fingerprint map can be derived from the stored Wi-Vi fingerprint. The Wi-Vi fingerprint map will be used for localization.

In the localization step, Wi-Fi and image will be collected for coarse localization, image-level localization, and metric localization. In coarse localization, it searches for candidate Wi-Fi fingerprints on the map using the proposed Wi-Fi fingerprint matching method and the K-nearest neighbors (KNN) algorithm. In image-level localization, it will extract the holistic features of the collected image, and match it with the features stored in the Wi-Vi fingerprint map using holistic visual features matching methods. Then, the GW-KNN (Gaussian weighted K nearest neighbor) method is applied to find the closest site from multiple feature spaces. In metric localization, it will perform local feature matching based on the result of image-level localization. Then, a threshold is established. If the number of matched key points exceeds the threshold, then proceed to perform homograph computation. Since the sign position is different from the position of the mobile device, homograph computation is applied to retrieve the pose of the mobile camera relative to the EXIT sign. The retrieved pose will be mapped into the global coordinate systems.

The proposed multiscale method enables quick and precise localization results, which is a suitable choice for implementation on smartphones with limited computing resources. The method can serve as a standalone positioning system or be used with existing methods. Real-time localization can be achieved by the proposed method on the smartphone and fewer localization errors. If OpenCV SDK is installed, the proposed algorithm can be easily integrated into other programs.

In literature [3], the Wi-Vi fingerprint method is specifically designed for indoor self-localization in public scenes with continuous EXIT sign distribution, which will restrict its usability to other scenarios. In addition, the method relies on a prebuilt map, making it unsuitable for use in un-inventory or dynamically changing environments. Besides that, the success of this method depends on the accurate placement of exit signs, which may require human effort and intervention. Furthermore, the performance might be impacted in more challenging real-world conditions, such as signal interference or varying lighting conditions.

2.3 Dead Reckoning-Based Method

The dead reckoning-based method utilizes different types of sensors, such as accelerometers, compasses, gyroscopes, and magnetometers to identify user position. A dead reckoning-based method is introduced, which is the inertial measurement unit (IMU) based pedestrian dead reckoning (PDR) method. It estimates the position and motion of the user using sensors from the smartphone.

2.3.1 Inertial Measurement Unit (IMU) Based Pedestrian Dead Reckoning (PDR) Method

In literature [7], an IMU-based PDR system that employs a smartphone was proposed. It uses different algorithms and sensors from the smartphone to recognize the user's motion.

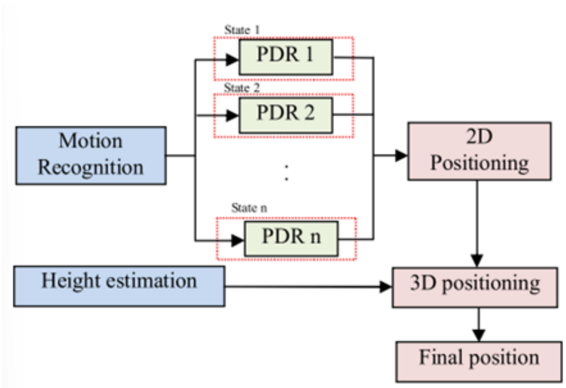


Figure 2.10 The system diagram of IMU-based PDR system [7]

Based on Figure 2.10, it applies a motion recognition algorithm with sensors from the smartphone to detect the user's walking status or motion. Then, it applies different PDR algorithms to recognize the detected motion pattern like the step length and heading at each detected step. The user height information is estimated using the onboard barometric pressure sensor of the smartphone. The height information integrates with the 2D position that is estimated by the motion recognition-based PDR to determine the 3D position of the user.

For the motion recognition algorithm, ANN and SVM are more suitable, but the implementation of the ANN is much easier than SVM. Besides that, ANN performs well in feature extraction and parameter tuning compared with SVM.

The positioning algorithm of the PDR includes step detection, step length estimation, and heading estimation. For step detection, the accelerometer is utilized to generate the RMS value and form a sinusoidal wave. To prevent false peak detection, the RMS value of the accelerometer signal applies a moving averaging filter. Then, the peak detection method is applied for step detection to detect the highest peak in a sinusoidal wave. According to the recognized motion as shown in Figure 2.11, different methods of step length estimation are applied for step length estimation. For heading estimation, the Kalman filter (KF) is applied to estimate the heading for M_2, while ANN is applied to estimate the heading for M_3 through M_6. Then, the time of the Kalman filter will be updated using the gyroscope, and the measurement will be updated using a magnetometer.

Motion ID	Motion explanation
M_1	Standing
M_2	Walking looking at the device
M_3	Walking swinging hands
M_4	Walking talking on the device
M_5	Running
M_6	Walking with the device in pocket

Motion ID	Step length estimation method	Step length
M_2	Real time estimation	SL
M_3	Using fixed step length	2 x SL_0
M_4	Using fixed step length	SL_0
M_5	Using fixed step length	SL_0 + 12(cm)
M_6	Using fixed step length	SL_0

Figure 2.11 List of Motions (Left), and Step Length Estimation and Method (Right) [7]

For the height estimation algorithm, the user’s height is estimated using the smartphone's barometric pressure. It also can differentiate which floor the user is located in a building. However, the barometric pressure sensor needs to be calibrated to estimate an accurate height by employing online sea-level pressure information and a true altitude from the GPS in an outdoor environment.

The IMU-based approach is cheaper and simpler because it does not require installation and maintenance of the infrastructure. The IMU-based approach has become more accurate and easier to implement because the sensors have been manufactured through the development of micro-electromechanical systems (MEMS). This approach can be enhanced by integrating with other approaches, such as GPS or Wi-Fi-based approaches.

However, users are required to maintain the smartphone orientation, so that it will not affect motion detection. Besides that, the motion classifier's accuracy drops during motion transitions, which may affect the performance during rapid changes in movement. In addition, the accuracy of height sensors relies on the availability and accuracy of external data sources. Other than that, this approach relies on smartphone sensors, which may limit its applicability to compatible hardware devices.

2.4 Critical Remarks of Previous Works

As discussed above, most indoor navigation methods have their advantages and disadvantages, as shown in Table 2.1.

<table>
<tr><th>Method</th><th>Advantage</th><th>Disadvantage</th></tr>
<tr><td>AR Marker</td><td rowspan="2">• Flexible to install new markers,delete markers, and update markers
• Can accommodate indoor changes
• Cost-effective
• Does not require powerful processors or devices
• Recognizes locations with similar appearance</td><td rowspan="2">• May fail in low- illumination environments
• Requires maintaining smartphone orientation
• Marker placement affects building aesthetics
• Affected by user walking speed</td></tr>
<tr><td>QR Code</td></tr>
<tr><td>CNN Recognition</td><td>• More accurate than the BLE approach
• Identifies static obstacles</td><td>• Affected by user walking speed
• May fail in similar appearance locations and low-illumination environments
• Requires maintaining smartphone orientation</td></tr>
<tr><td>ViNT</td><td>• Adaptable and efficient model
• Only require minimal data for fine- tuning
• Control new robots without prior training or performing indoor mapping
• Handles large-scale navigation</td><td>• Higher computational demand
• More expensive deployment than simpler models
• Need large training data and action to build the model</td></tr>
<tr><td>BLE Fingerprint Positioning</td><td>• Low cost, low power consumption, and fast connection.
• Feasible with most Bluetooth devices.
• Effective for getting real-time position
• Not affected by user walking speed</td><td>• Unable to detect an obstacle
• Less accurate than the vision-based method
• Short battery life of Bluetooth beacons</td></tr>
<tr><td>Wi-Vi Fingerprint</td><td>• Fast and accurate localization
• Can work independently or with other methods</td><td>• Not suitable in frequent change environments</td></tr>
</table>

	• Easily transplanted with OpenCV SDK	• Affected by lighting conditions and signal interference • Limited to scenes with EXIT sign distribution • Performance may be impacted by real-world conditions
IMU-based PDR System	• Cheaper and simpler • No infrastructure installation • Can be integrated with other approaches	• Requires maintaining smartphone orientation • Accuracy drops during motion transition • Height sensor accuracy depends on external data sources

Table 2.1 Advantages and disadvantages of methods for indoor navigation

2.5 Proposed Solutions

This project aims to propose an application that allows users to navigate in indoor spaces. Based on Table 2.1, the marker-based approach is suitable for the application, since it is flexible enough to accommodate indoor changes at a low cost. It also is not affected by the similar appearance of an indoor environment. In addition, it does not require a powerful device, which is suitable for the public, and particularly handy for blinders. With the use of fiducial markers, the application can track the location of the user accurately and effectively. The application also needs to provide audio instruction to assist users, particularly blind people.

Chapter 3

System Methodology and Design

In this chapter, it will give an overview of the system to show how users and implemented software interact with the system. Besides that, the implemented fiducial marker, ArUco marker, will be discussed in this chapter. The system design will be discussed to show the included functions and how they work.

3.1 System Overview

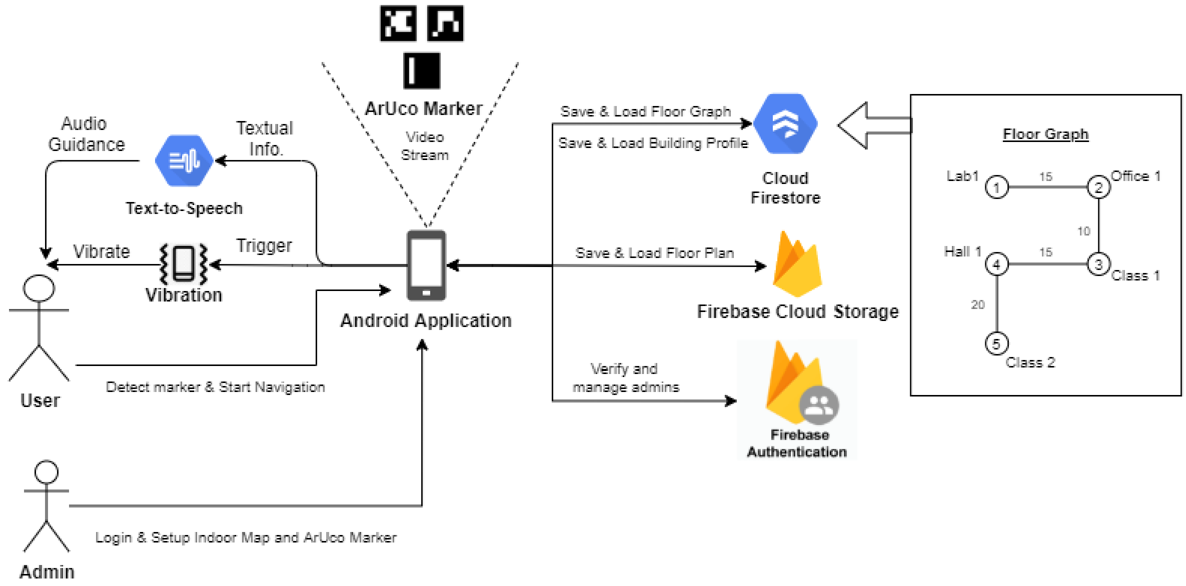


Figure 3.1 System Overview of the indoor navigation system

As shown in Figure 3.1, there are two characters involved in the system, which are user and admin. In order to identify the administrator, Firebase Authentication is implemented to verify and manage the administrator account.

An admin is responsible for setting up the indoor map of the building into the system and creating markers. This will include the image of the floor plan which will stored in the Firebase Cloud Storage since it is unstructured data. The admin will create a floor graph based on the floor plan. The floor graph is a data structure, which defines the layout of the markers placed in the indoor environment. The nodes represent markers and the edges or connections represent the path. Then, the floor graph will be stored in the Cloud Firestore together with building profiles.

In the user's case, it uses an application to detect the marker placed in the indoor space and select a destination for navigation. The application will request access to the user's camera and detect the marker in the form of a video stream. The application will provide audio guidance to the user based on the textual information. The textual information includes the name of the current location of the user and the direction in which the user should move it. Besides audio guidance, vibration is utilized to ensure that the user moves in the correct direction during the navigation. Thus, the system provides a multi-sensory experience for guidance. Lastly, the application is only supported on Android mobile devices.

3.2 ArUco Marker

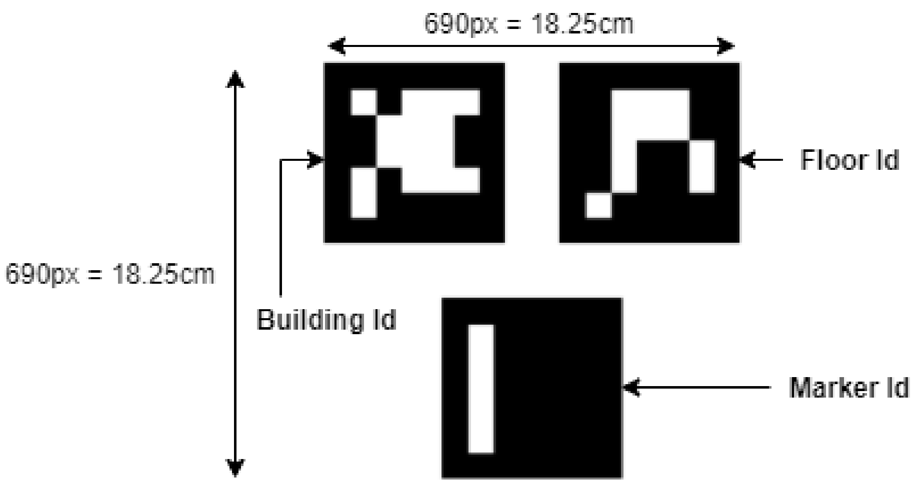


Figure 3.2 ArUco Marker

ArUco marker and detection originates from OpenCV library, which is useful for easy, fast, and accurate camera pose estimation [11]. In our case, the marker is used to identify the user's location during navigation. The types of ArUco markers and detection depend on the predefined dictionary they specify, predefined dictionary such as DICT_6X6_250, DICT_4X4_250, etc. This is important because it defines the size (in bits) of markers and the limit on the number of markers that can be created. In addition, the marker detection can only detect those markers that have the same dictionary as itself. For instance, DICT_4X4_250 marker detection can only detect DICT_4X4_250 markers. In our case, it uses the DICT_ARUCO_ORIGINAL dictionary to create the marker and detection.

For the application, it uses a customized marker with a size of 18.25cm x 18.25cm as shown in Figure 3.2. The customized marker is a combination of three ArUco markers that consist of different information, which are building id, floor ID, and marker id. However, it has a limit on the number of markers, with a maximum of 500 markers per floor. Since this is a combination of ArUco marker, we will still name it ArUco marker in the following chapter.

3.3 System Design

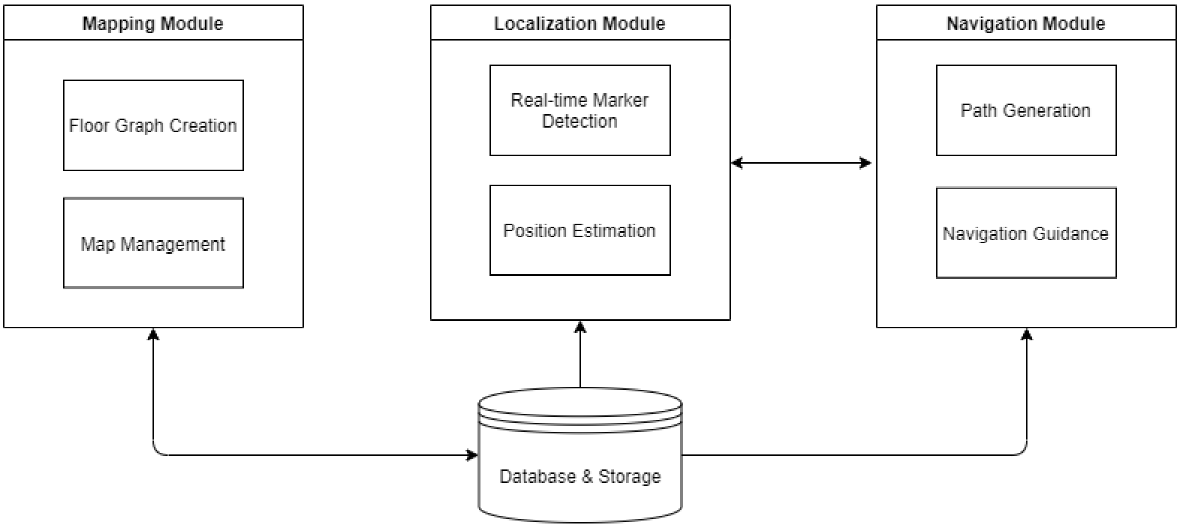


Figure 3.3 System design of the indoor navigation system

As shown in Figure 3.3, the system design of the indoor navigation system consists of three modules, which are the mapping module, localization module, and navigation module. The mapping module is responsible for creating a floor graph and managing the building profile and floor graph, and the floor graph will be stored in the database. The localization module uses the mobile camera to detect markers in real-time in the indoor environment and estimate the user location based on the detected markers and the existing floor graph of the location. The navigation module calculates the shortest route and continuously guides the user during navigation.

3.4 Mapping Module

This module includes floor graph creation and floor graph management. In addition, this module can only allow the admin to access it. Floor graph creation allows admins to create a new floor graph, while map management allows admins to manage the existing floor graph and building profile.

3.4.1 Floor Graph Creation

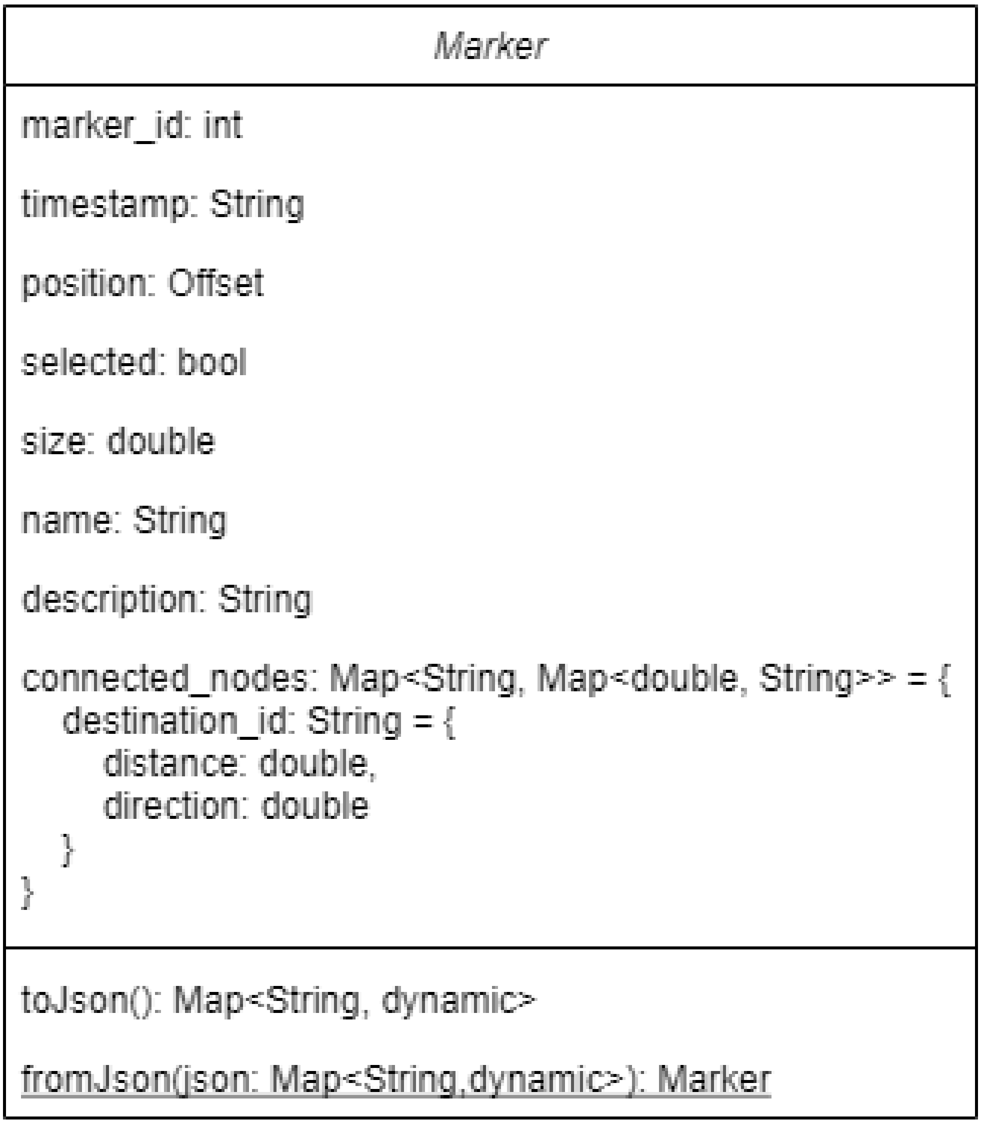


Figure 3.4 Marker Class

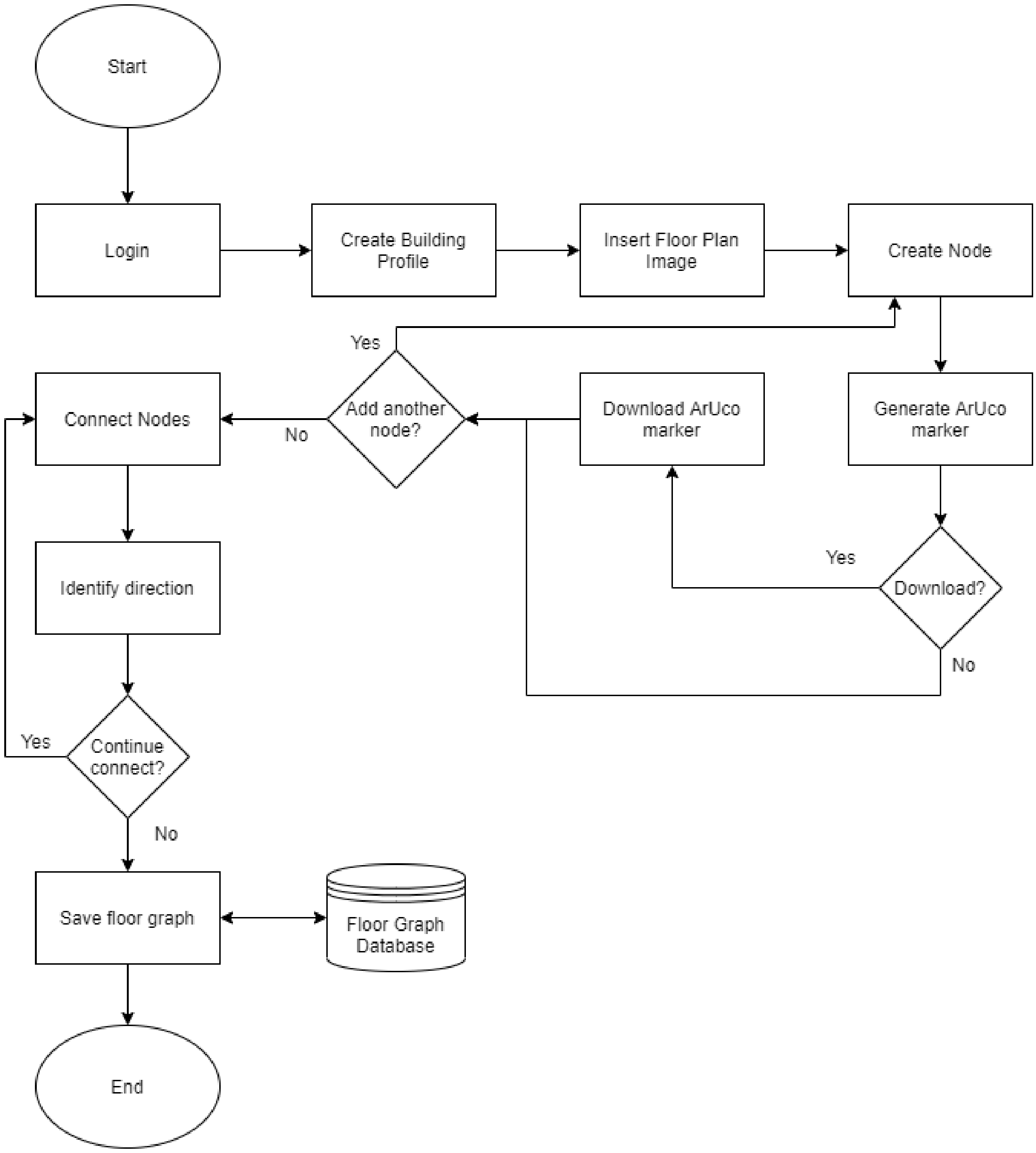


Figure 3.5 Floor Graph Creation

This sub-module is responsible for creating the representation of indoor space in the form of a floor graph. As shown in Figure 3.4, each node will store information such as location coordinates, connection information like distance and direction, location description, created date time, and name. As shown in Figure 3.5, users are required to log in because only admins are allowed to enter the mapping module. The admin will create a building profile first, then insert the floor plan of the building according to their respective floors. Based on the floor plan, admins can create a new node on it. First, admins are required to select the location on the floor plan to add the node. Then, admins need to insert the name and description of the node. At the same time, a unique ArUco marker is generated, and it allows admins to download it to their local device to print it out. After the node is added to the floor plan, admins can connect the existing nodes to form possible paths. However, connecting a node requires determining the direction from the starting node to the node selected for connection. Thus, the application will provide a function to access the mobile phone compass and get the direction. Once admins complete the creation, the floor graph will be stored in the database, while the floor plan will be stored in the storage.

3.4.2 Map Management

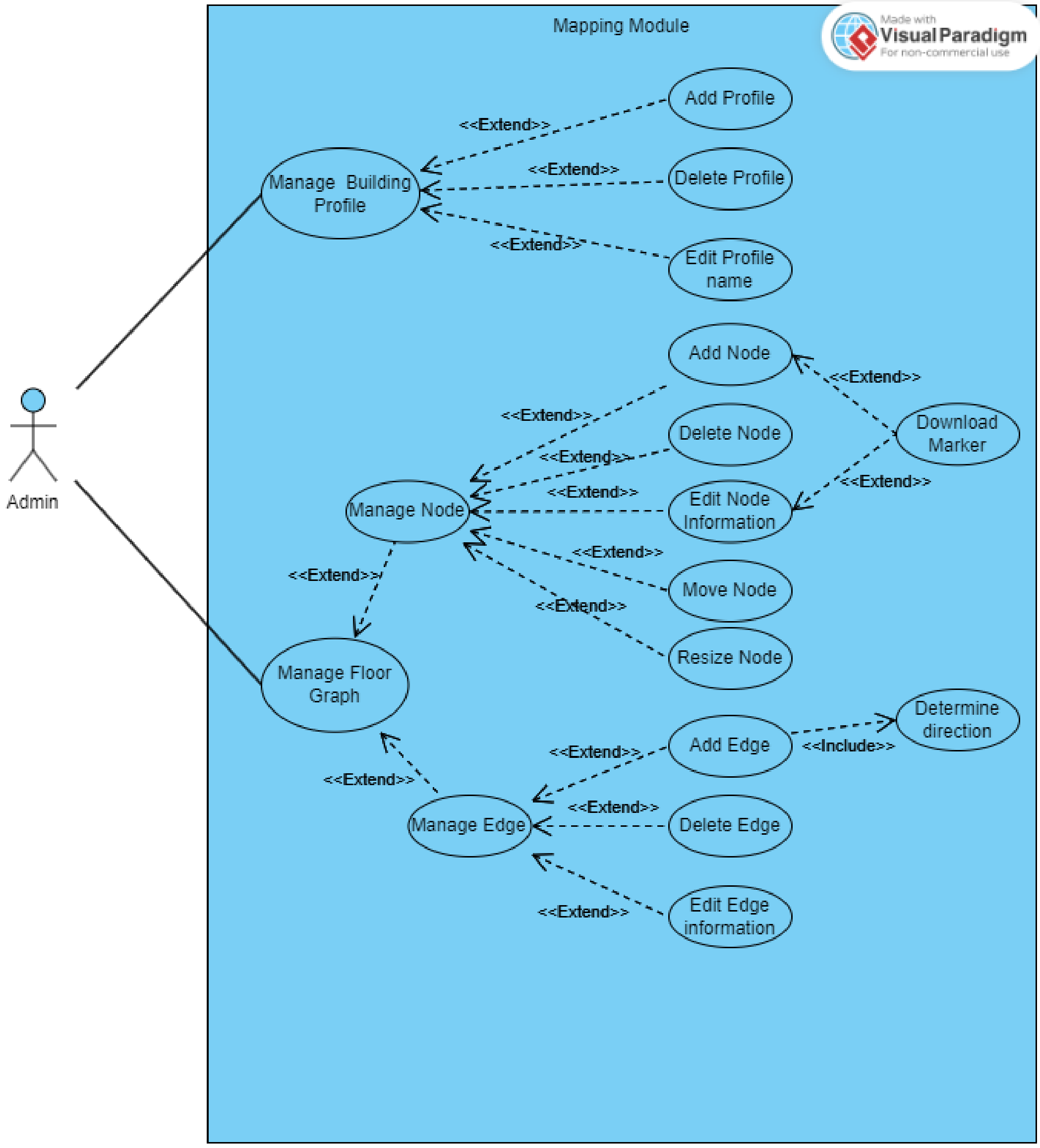


Figure 3.6 Use case diagram for Map Management

This sub-module allows the user to manage the existing floor graph and building profile. This may be necessary when the indoor environment or building profile has any changes or new markers are added. As shown in Figure 3.6, this sub-module allows users to perform several actions to manage the floor graph, including updating the marker and path information, removing the existing nodes and edges, and extending the existing floor graph with new nodes and edges. When the printed marker is spoiled or missing, the admin can download again the respective marker. The admin also can reposition and resize the node on the floor plan to ensure the position of the node is correct. However, this action can be done when the node is not connected with any other node. In addition, the admin can manage the building profile, including adding a new profile, removing an old profile, and editing the profile name.

3.5 Localization Module

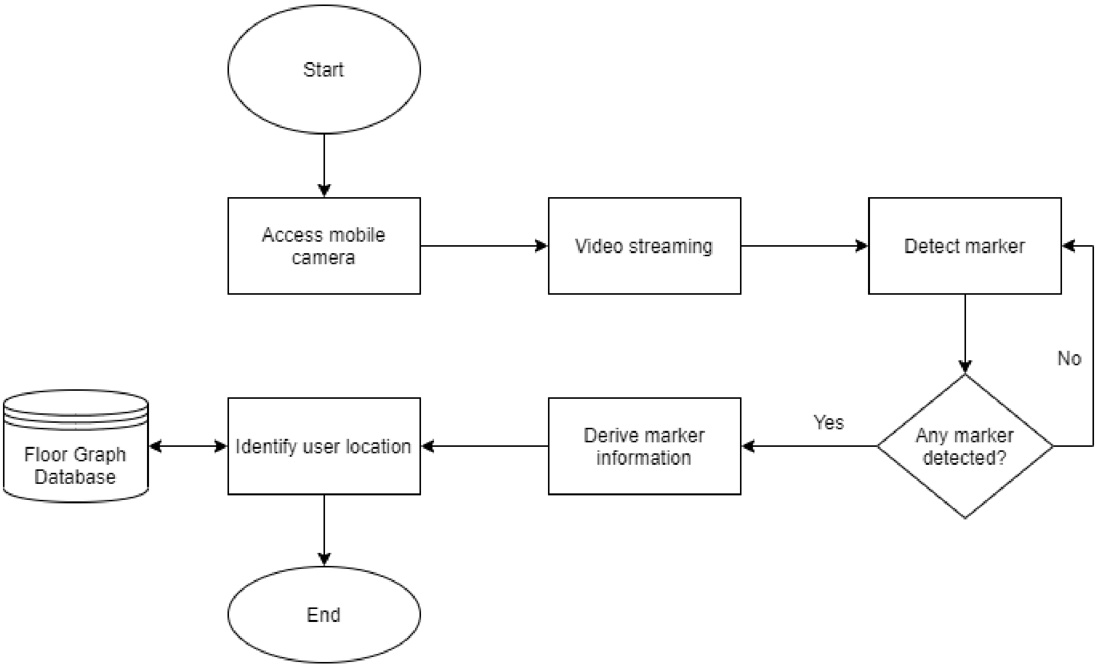


Figure 3.7 Localization module flowchart

The module includes real-time marker detection and position estimation to continuously detect markers in the indoor environment, and identify the user's position according to the derived marker information and floor graph.

3.5.1 Real-time Marker Detection

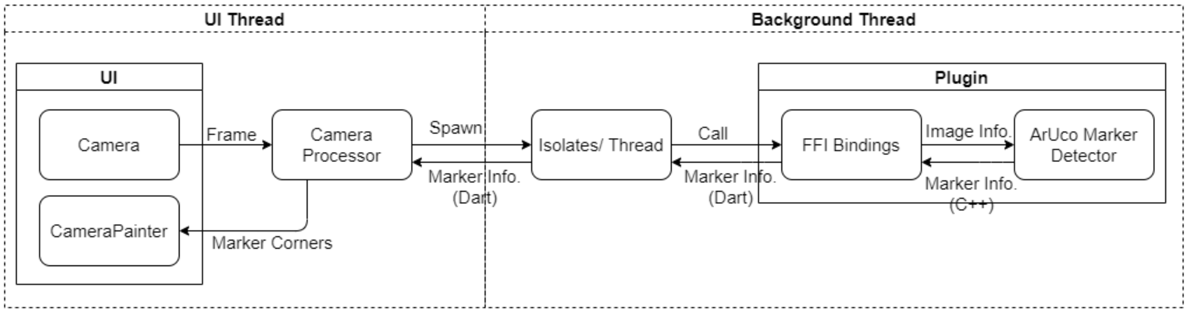


Figure 3.8 Real-time Marker Detection

The localization module uses a mobile camera and ArUco marker detection to continuously detect the presence of markers placed in the environment. The implemented ArUco marker detection is configured to detect ArUco markers created by the system. As shown in Figure 3.8, it will get the frame of the camera and pass it to the processor. Then, the processor will spawn a thread to do the processing in the background like converting the YUV image to an RGBA image, so that it will not block the UI running. Then, the thread will run the ArUco marker detector asynchronously. To do so, FFI (foreign function interface) binding is implemented to provide an interface for communication between the native code like C++ and Flutter Dart code. Once the detector detects a marker, it will return the marker information, including the position of the marker corners. Based on the marker corners, the camera painter will draw out the contour of the marker.

3.5.2 Position Estimation

Once a marker is detected, it will derive information like building ID, floor ID, and marker ID from the marker. Then, the derived information will be used to determine the user's location. Then, the system will use the derived information to load the respective floor graph and identify the user's location according to the floor graph. Then, the results will be passed to the navigation module to assist the navigation.

3.6 Navigation Module

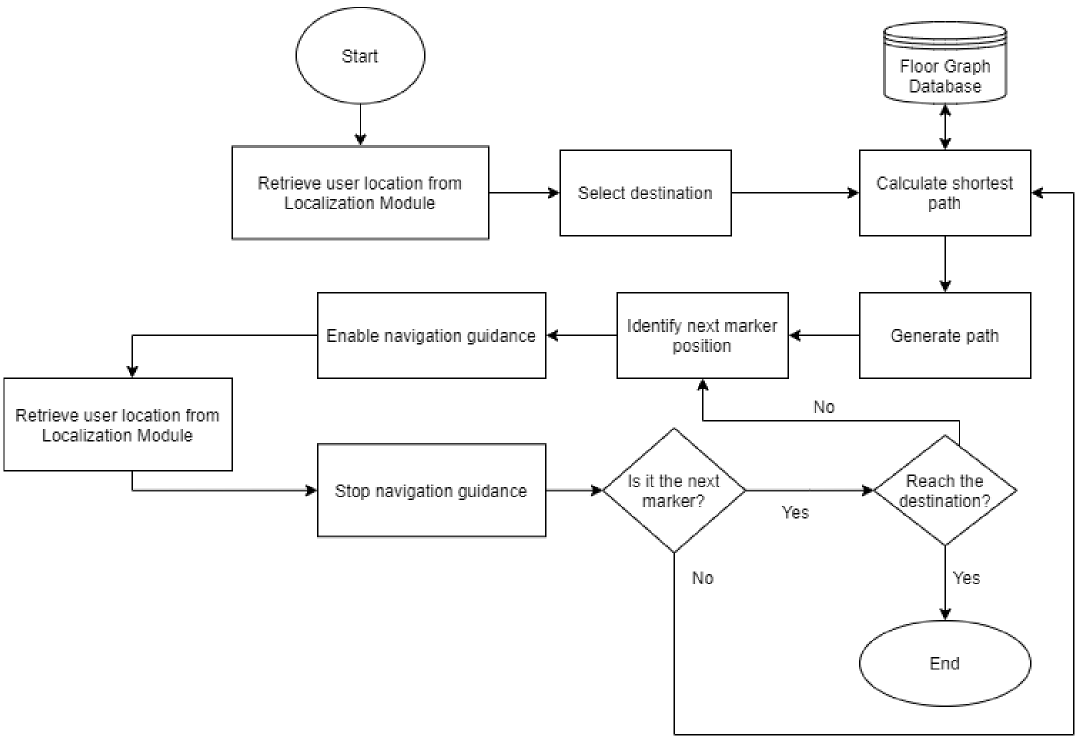


Figure 3.9 Navigation module flowchart

This module generates the shortest path from the current location to the destination and continuously guides the user during navigation. This module will collaborate with the localization module to retrieve the user's position in the indoor environment.

3.6.1 Path Generation

Before the path generation starts, it requires retrieving the user's current location in the indoor space from the localization module and requires the user to select the destination that exists in the floor graph. After determining the user's current position and destination, the navigation module calculates the shortest path to reach the destination in the corresponding floor graph through Dijkstra's algorithm. Dijkstra's algorithm is an algorithm that finds the shortest paths between nodes in a weighted graph, while the weight in the floor graph is the distance of the path. According to the calculation, the path will be generated.

3.6.2 Navigation Guidance

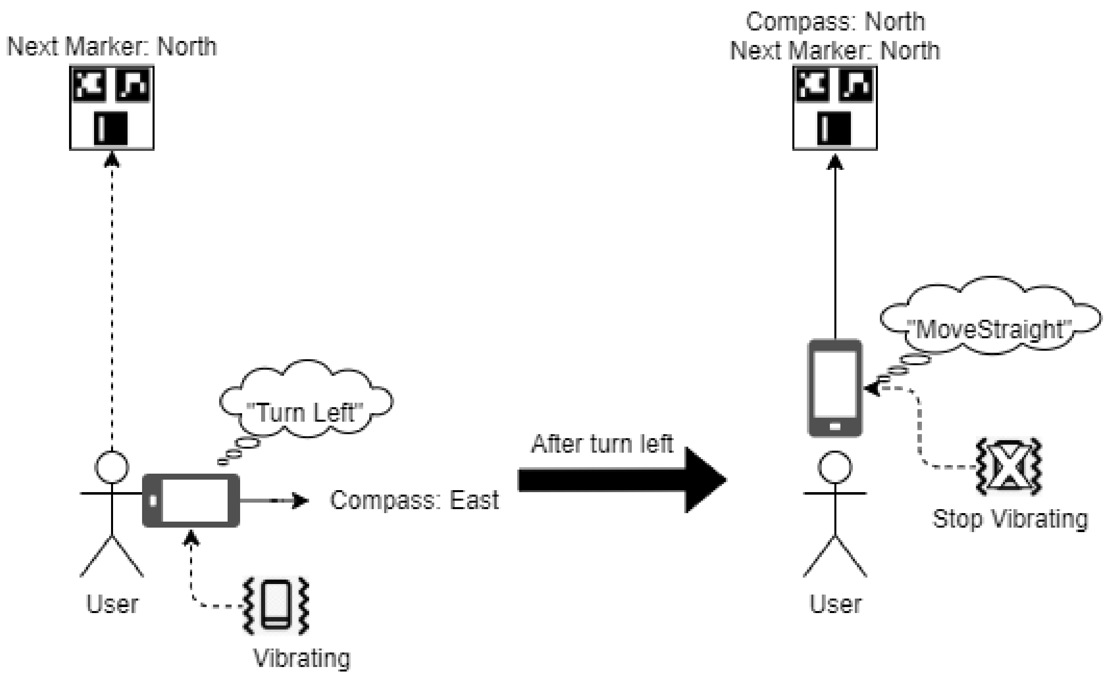


Figure 3.10 Navigation Guidance

After the path is calculated, the system will identify the next marker position and enable this function. Based on the next marker position, this function will use audio, compass, and vibration to continuously guide the user to move in the right direction during the navigation. With the help of a compass, it will identify the facing direction to the next marker. Then, it will generate audio instructions to guide the user to face the correct direction. The vibration will be triggered when the user faces the wrong direction. Once the user reaches the next marker, this function will stop and resume when the next marker is identified.

If the user detects the wrong marker, then it will re-route the path again based on the current position. If the user successfully reaches the next marker but not the destination, then it will identify the next marker again. The navigation ends once the user successfully arrives at the destination.

Chapter 4

System Implementation

In this chapter, it will discuss the specification of hardware and the use of software that is involved in the development. Then, it will introduce how the system operates for both user and admin.

4.1 Hardware

The hardware involved in this project is a computer and Android mobile device. A computer was issued for the development process. A mobile device is used for testing and deploying this application.

Description	Specifications
Model	Acer Nitro AN515-45
Processor	AMD Ryzen 5 5600H with Radeon Graphics, 3301 Mhz, 6 Core(s), 12 Logical Processor(s)
Operating System	Windows 10
Graphic	NVIDIA GeForce GTX 1650 4GB GDDR6
Memory	8GB DDR4 RAM
Storage	512GB SSD

Table 4.1 Specifications of Laptop

Description	Specifications
Model	Samsung A135F/DS
Processor	Octa-core (4x2.0 GHz Cortex-A55 & 4x2.0 GHz Cortex-A55)
Operating System	Android 13
Graphic	Mali-G52
Memory	6GB RAM
Storage	128GB

Table 4.2 Specifications of Mobile Device

4.2 Software

Tools	Purpose
Visual Studio Code	Utilize this platform to build the mobile application
Visual Studio 2017 + OpenCV 4.5.1	Utilize this platform and library to build the marker detection.
Android Studio	Utilize this platform to create a virtual device
Firebase Cloud Storage	A cloud-based NOSQL storage to store the floor plan that is uploaded by the user
Cloud Firestore	A cloud-based database to store the building profiles and floor graphs for each floor of each building
Firebase Authentication	A backend service to authenticate admin to access the mapping module of the application

Table 4.3 Software Tools

4.3 System Operation

4.3.1 Marker Detection Page

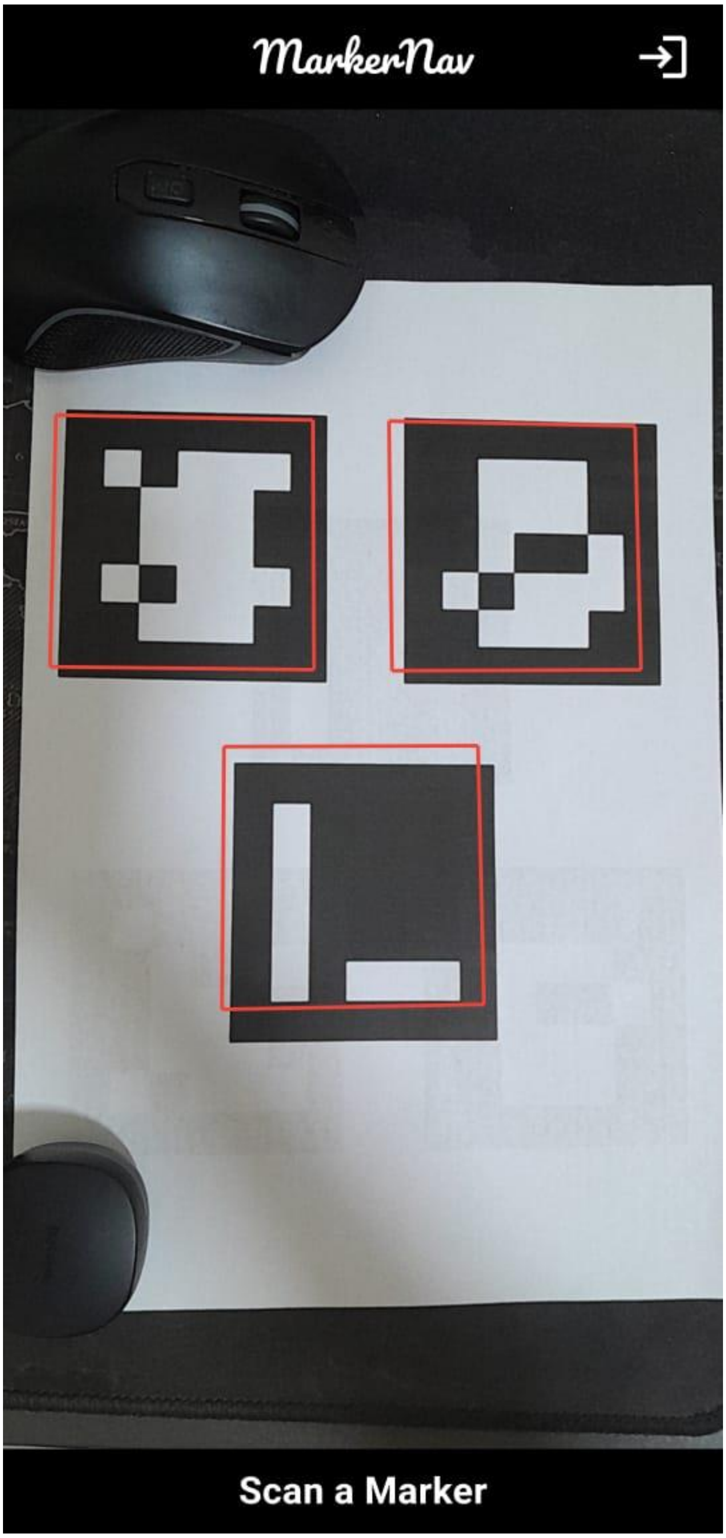


Figure 4.1 Scan Marker

Figure 4.1 is the page after the user enters the application. It will request access to the camera of the user's device to scan ArUco markers created by the system. The button in the top right corner allows the admin to log in to the mapping module.

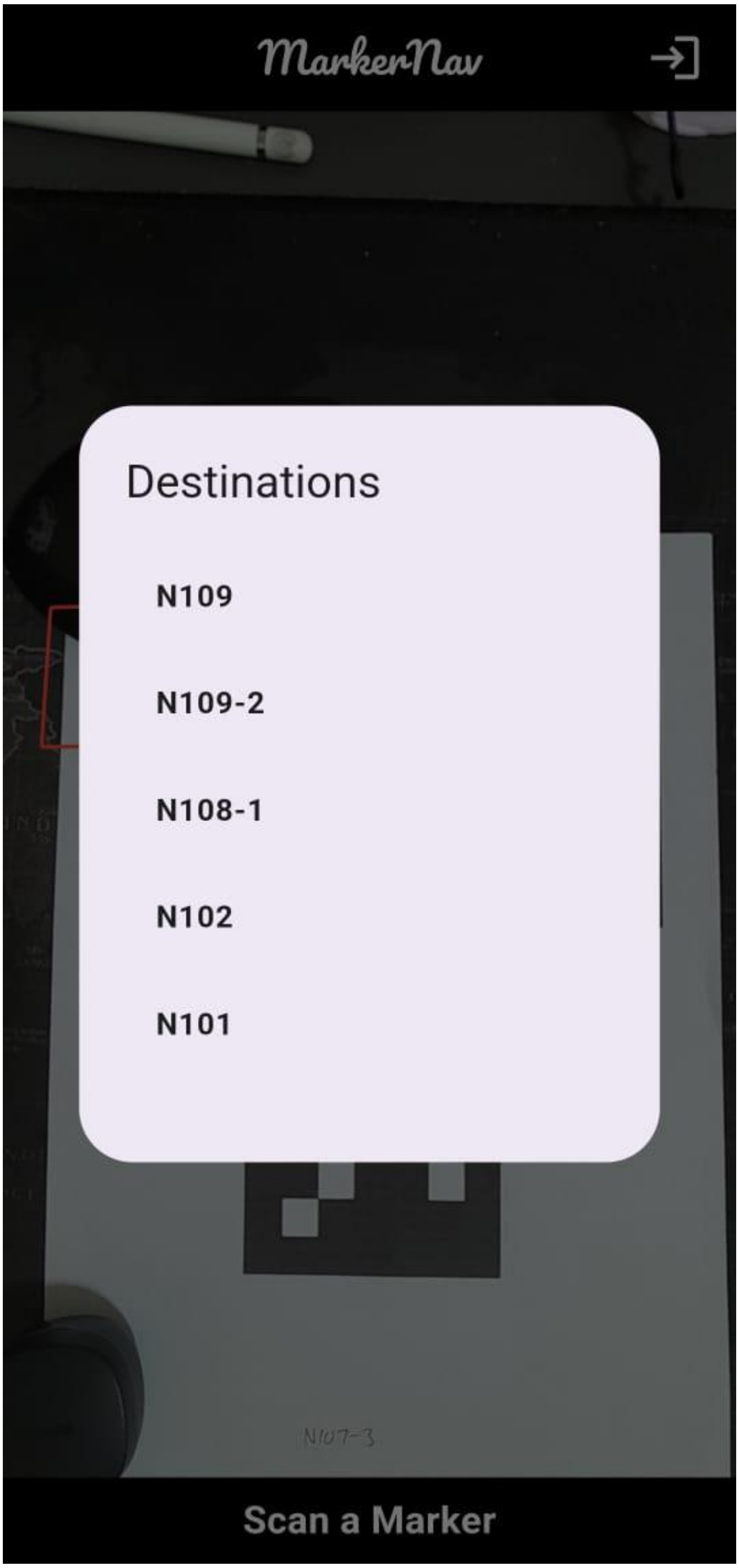


Figure 4.2 Destination Option

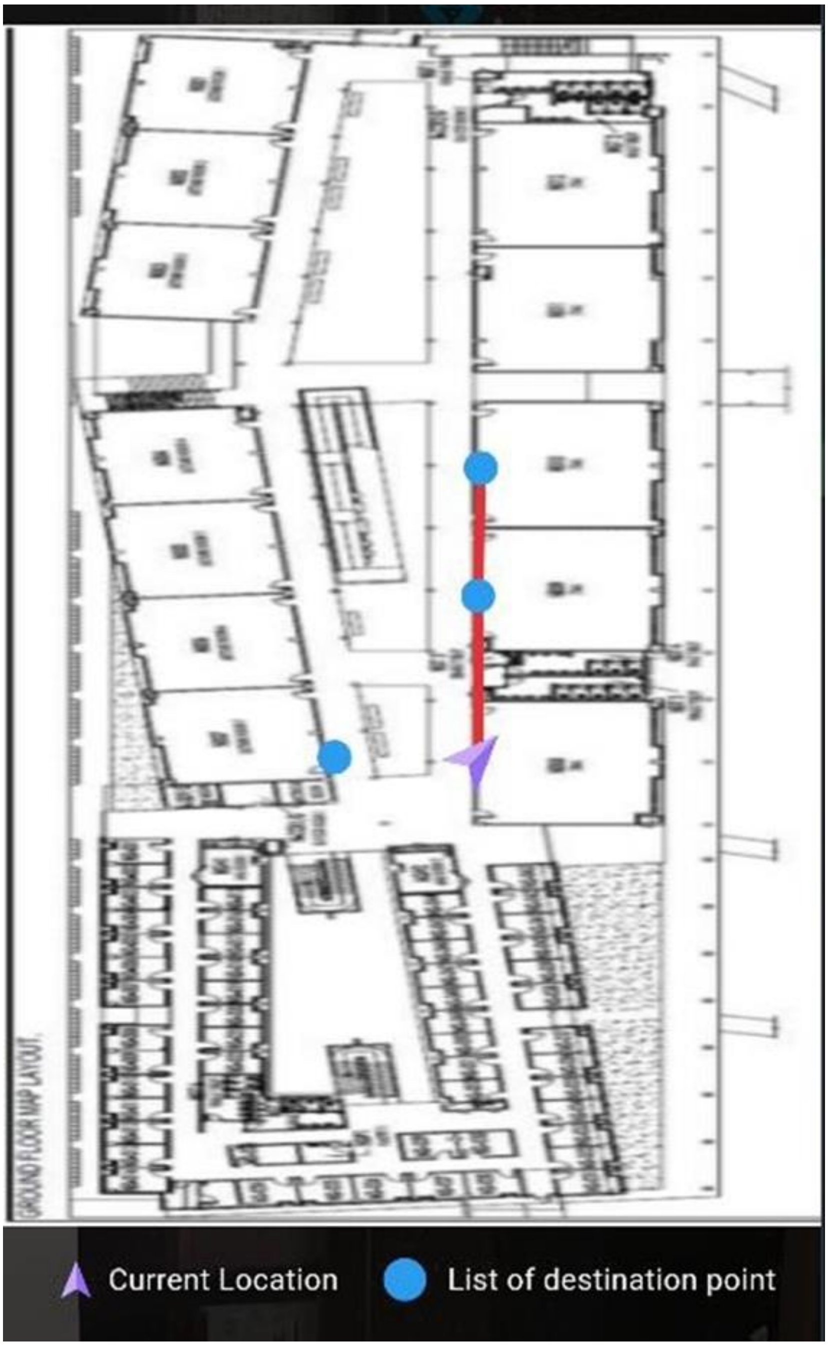


Figure 4.3 Navigation Path

Once the user scans a marker, it will derive the result and identify the user's position and respective map. As shown in Figure 4.2, it will prompt a list of destinations to let the user select. Once the user selects a destination, it will generate the shortest path calculated by Dijkstra’s algorithm and start the navigation, as shown in Figure 4.3. During the navigation, audio guidance will be provided, such as “Turn Left”, “Turn Right”, “Stop” and “Move Straight”. Plus, vibration will be triggered when the user facing the wrong direction.

4.3.2 Login Page

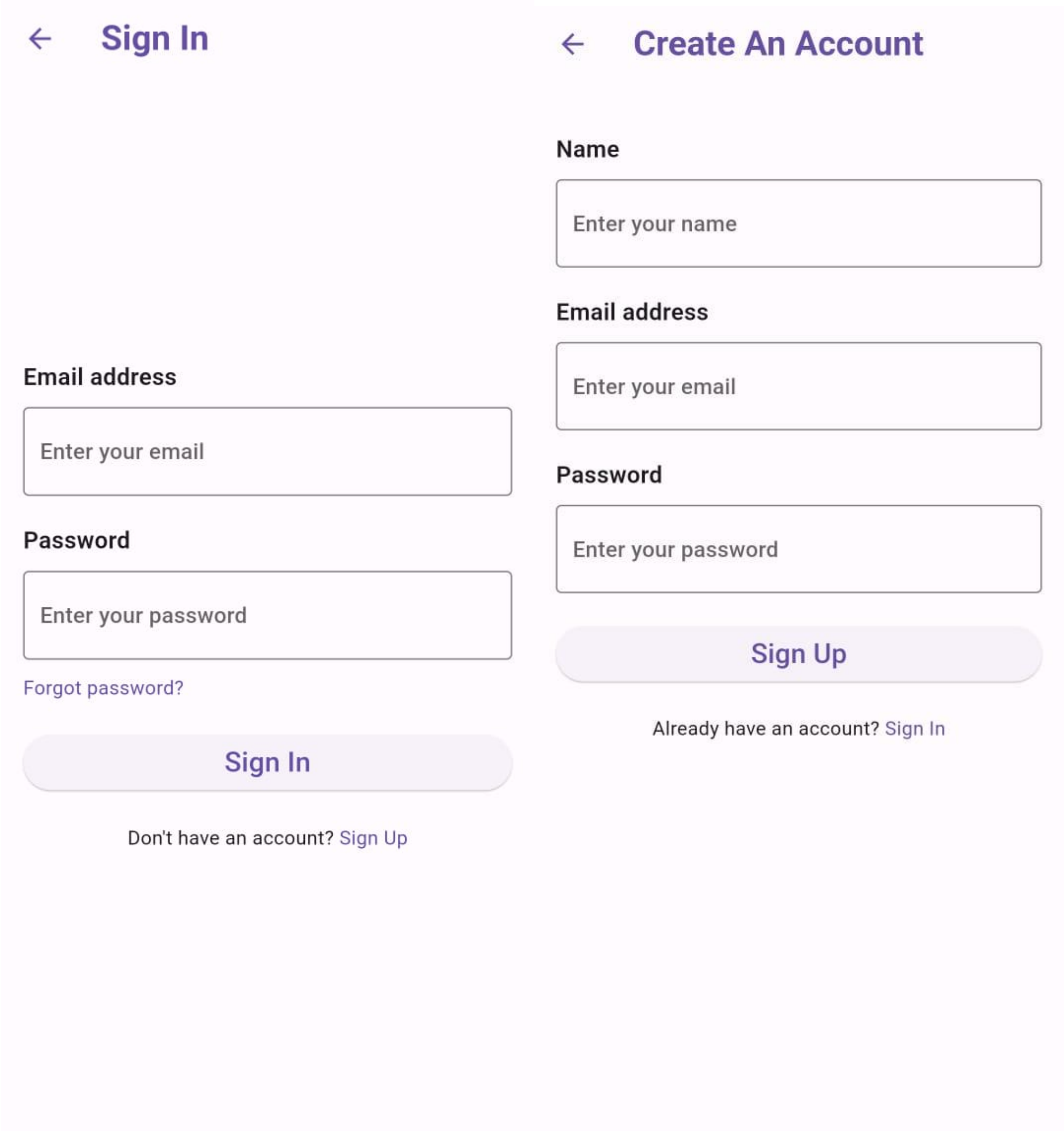


Figure 4.4 Sign-In (left) and Sign-Up (right) page

Before the admin enters the mapping module, it requires them to sign in to their account first. If the admin does not have an account, the admin can register an account and wait for approval. If any admin forgets his password, the admin can click the "forget password" button and wait for an email to reset its password.

4.3.3 Building Profile Page

Figure 4.5 Building Profile page

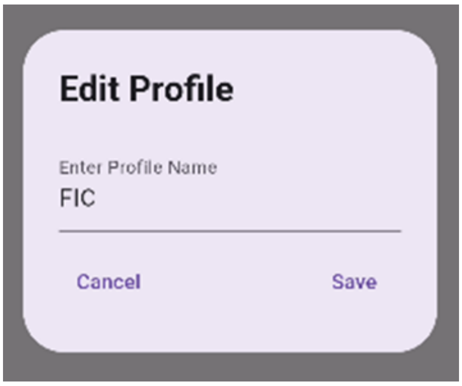


Figure 4.6 Edit profile

When the admin enters the mapping module, it will show the building profile page which allows the admin to add, edit, and delete the building profile. However, the admin only can edit the profile name as shown in Figure 4.6.

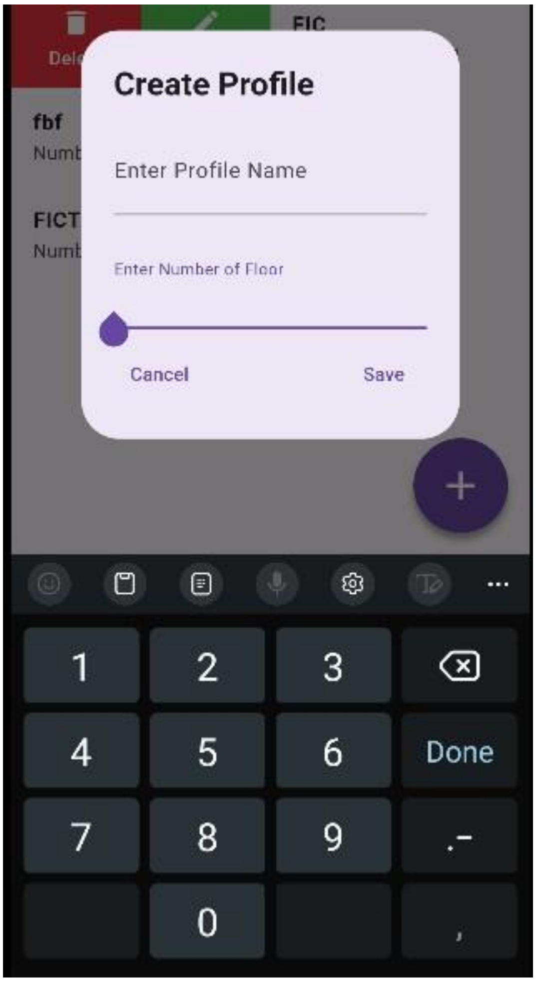


Figure 4.7 Create a profile

When the admin wants to create a building profile, it is required to enter the name and the number of floors of the building. The 'Number of Floor' field will only prompt the number keypad and does not allow to paste of any text to prevent text from entering the field.

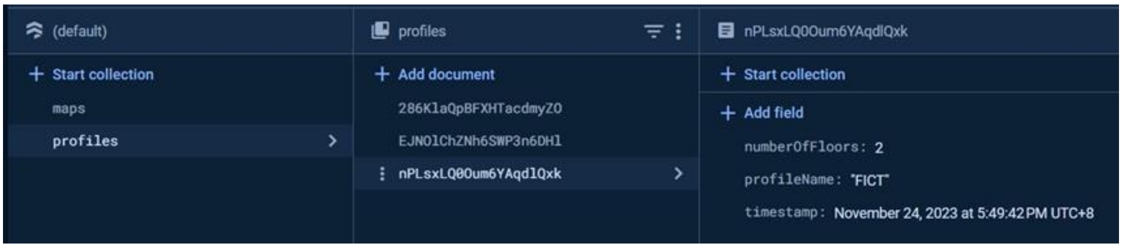


Figure 4.8 Building profile stored in Cloud Firestore

Once it saves the information, it will store it in the Cloud Firestore. If either one or both fields are empty, it will prompt an error message. Besides that, a message will be prompted when the building profile exists based on the profile name. Similar to 'Edit profile' as shown in Figure 4.6, it will also check the edited name whether exists.

4.3.4 Floor Graph Page

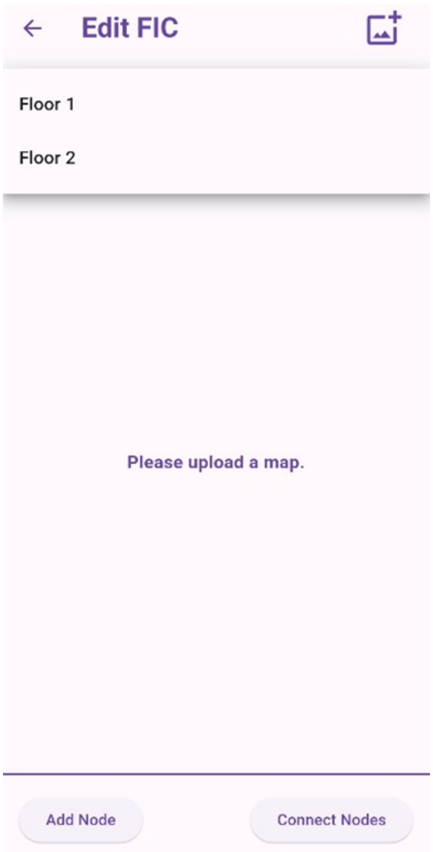


Figure 4.9 Floor graph page

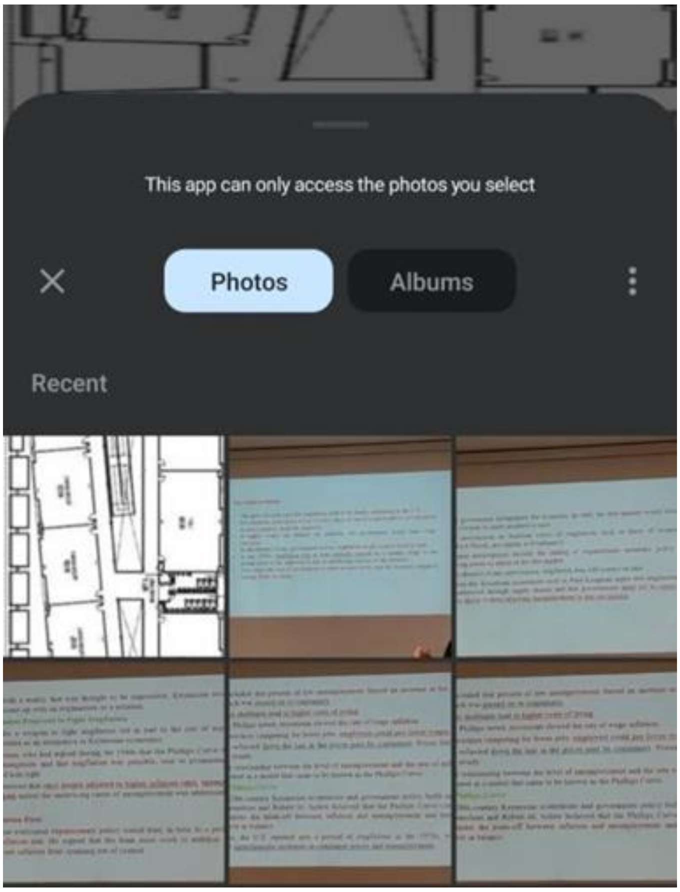


Figure 4.10 Insert floor plan

Figure 4.11 Floor plan stored in Firebase Cloud Storage

Once the admin selects a profile, it will enter the floor graph page to create or manage the floor graph on different floors. The top right corner button allows the admin to insert the floor plan from the local device, and store into the storage, as shown in Figure 4.11. The button in the lower left corner is used to add new nodes, and the button in the lower right corner is used to connect nodes.

4.3.5 Add Node

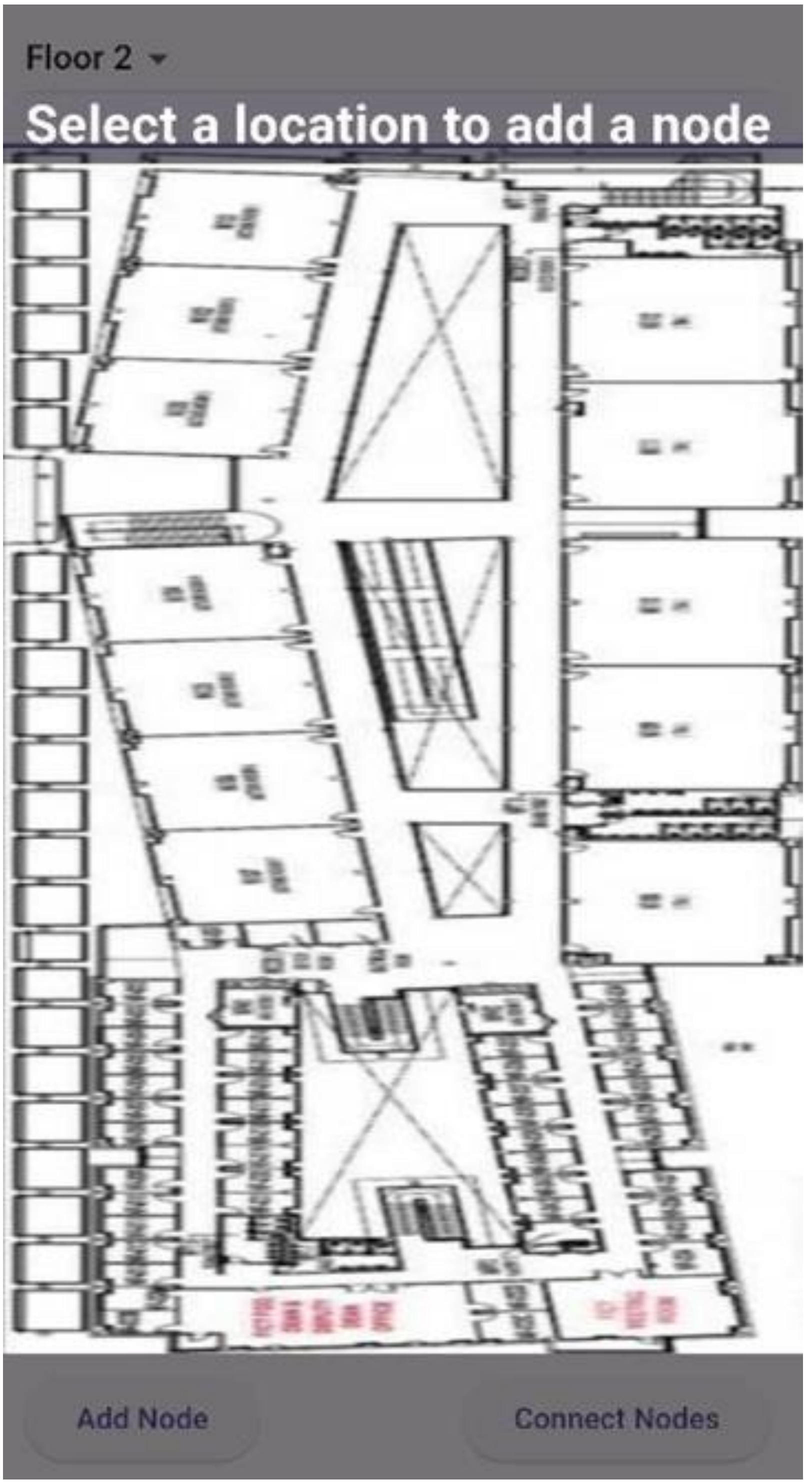


Figure 4.12 Select the position to add the node

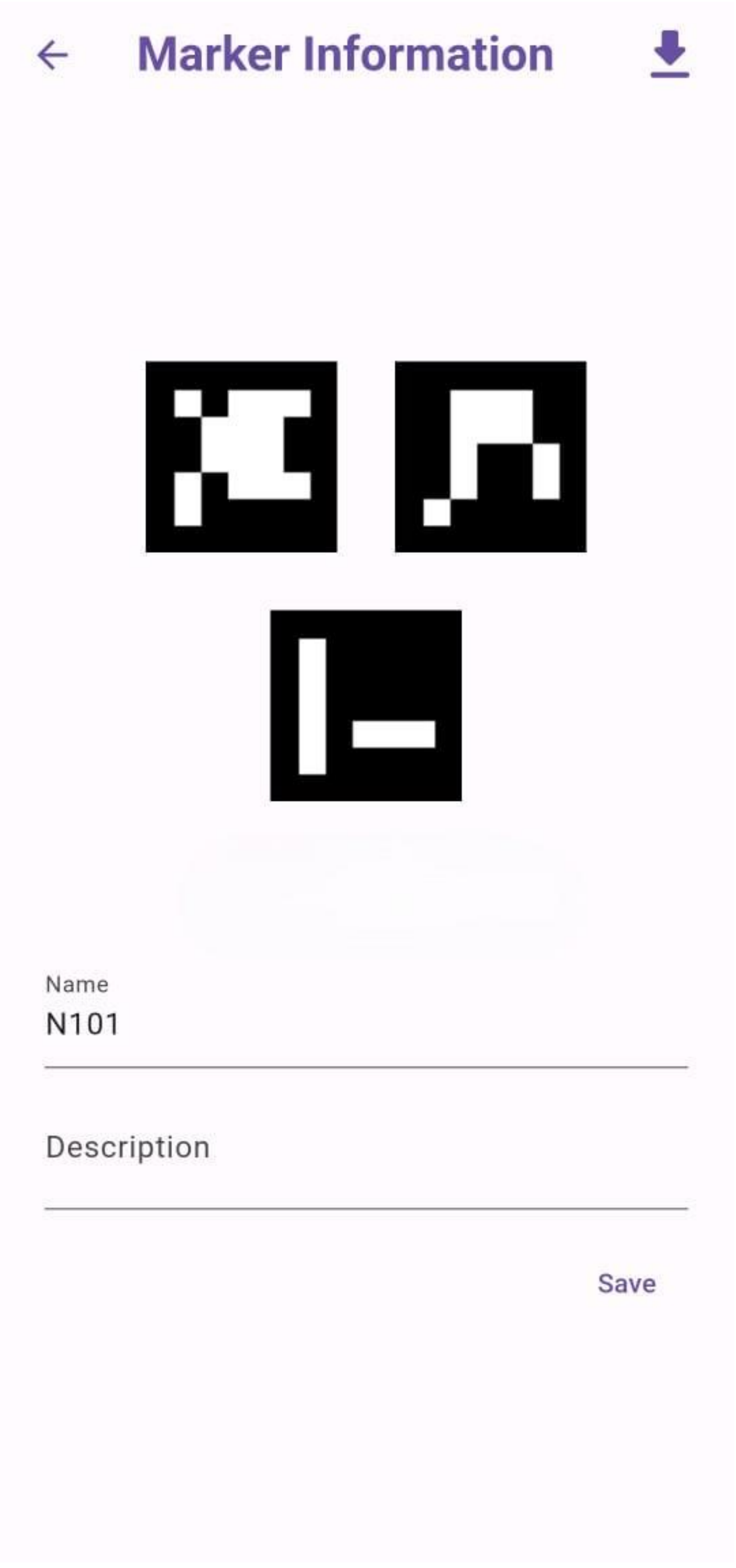


Figure 4.13 Node information along with ArUco Marker

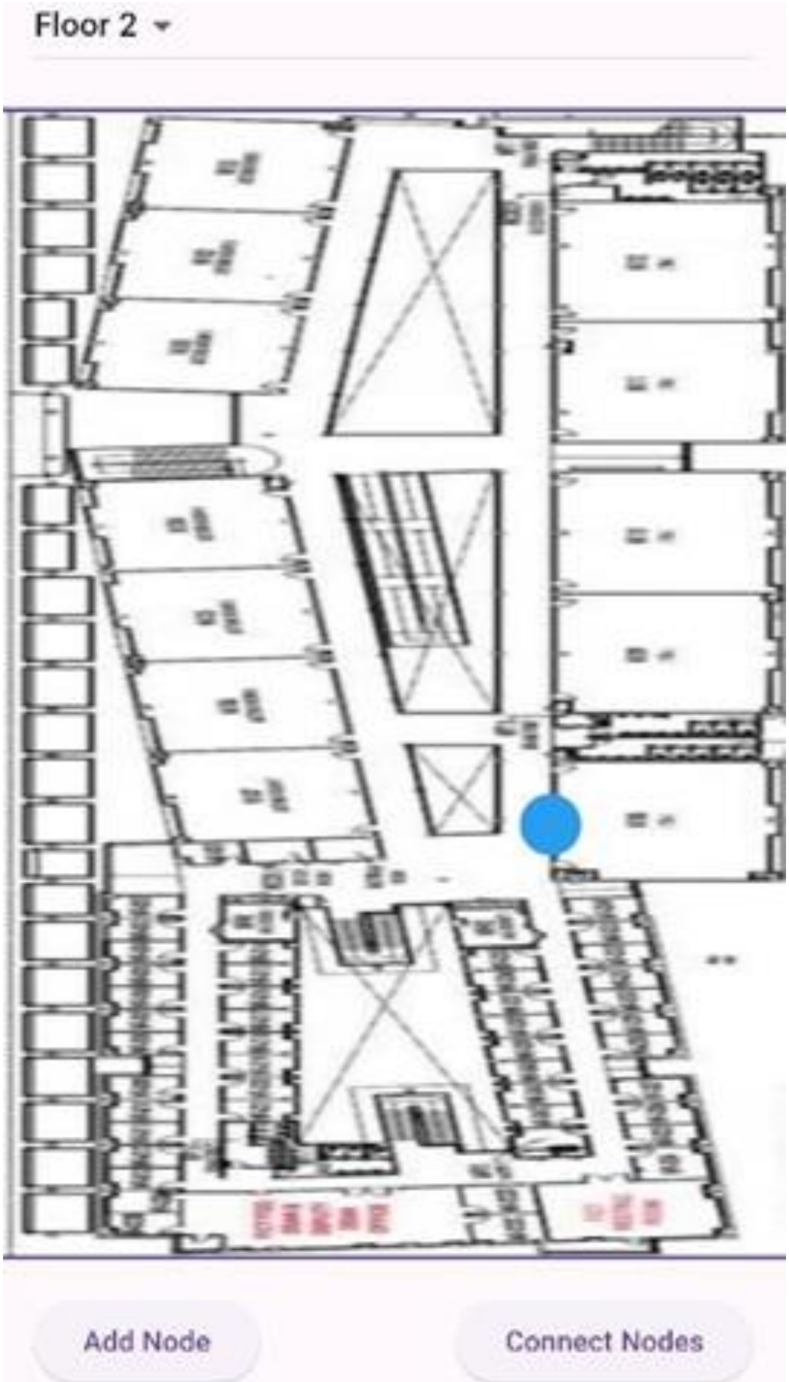


Figure 4.14 Node added

When the admin chooses to add a new node, the admin needs to choose the location to add the node, as shown in Figure 4.12. Then, the admin needs to enter the information of the node, as shown in Figure 4.13. An ArUco marker also will be given, and the button in the top right corner allow the admin to download the ArUco marker to the local device. As shown in Figure 4.14, the node was added on top of the floor plan.

4.3.6 Connect Nodes and Manage Edges

Figure 4.15 Select nodes to connect

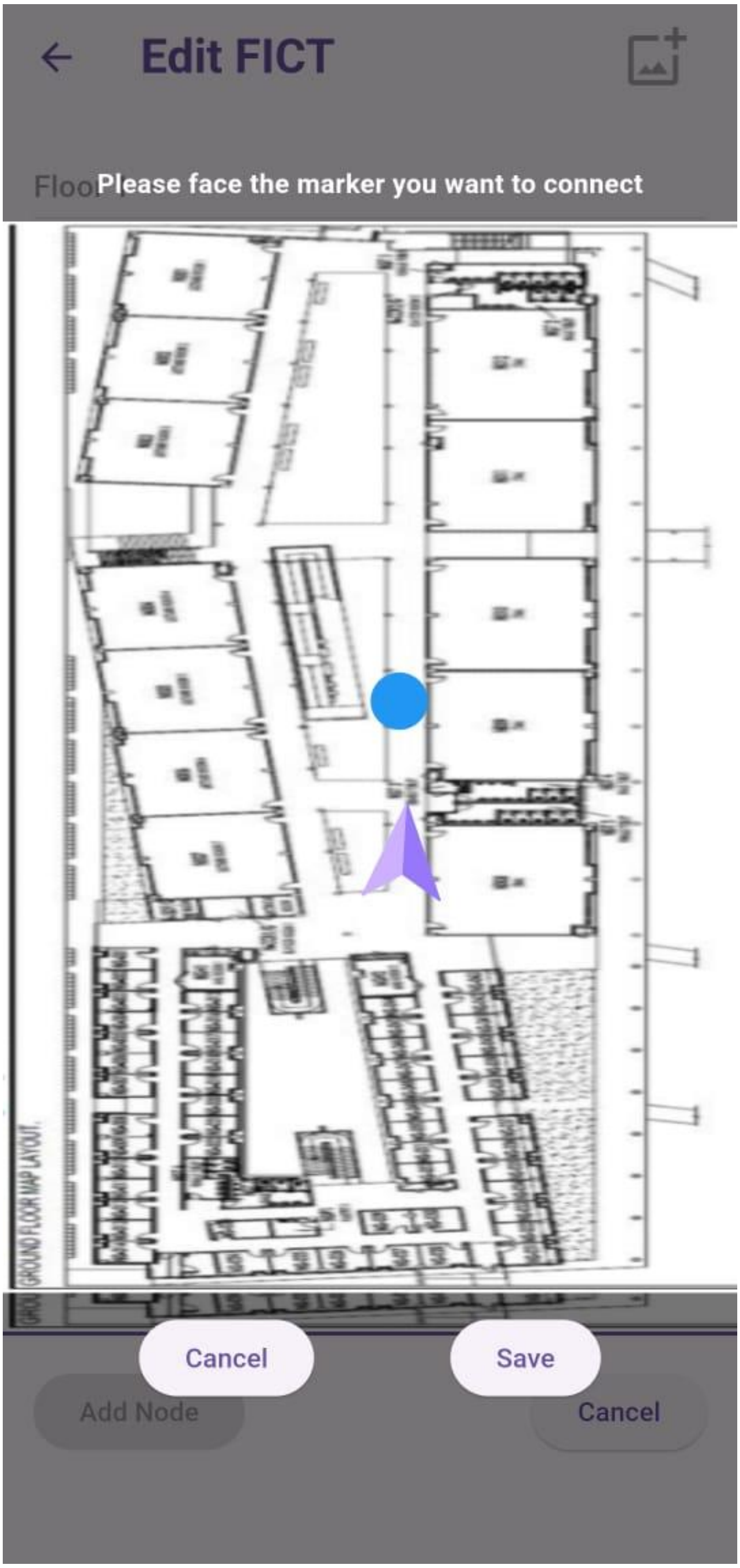


Figure 4.16 Identify direction

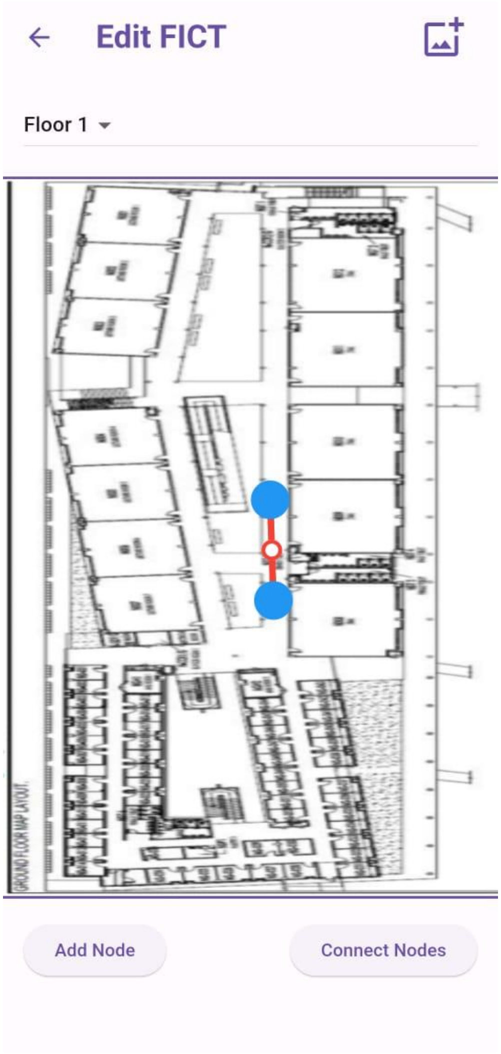


Figure 4.17 Nodes connected

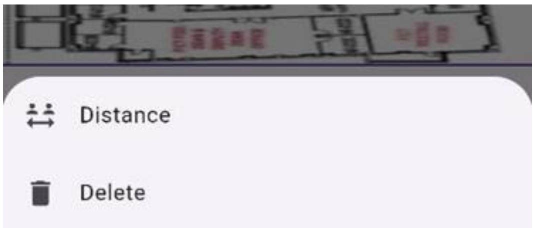


Figure 4.18 Menu for an edge

When the admin chooses to connect a node as shown in Figure 4.15, the irrelevant button will be disabled and the starting node will turn orange. Once the admin can select a node to connect it, it will require the admin to identify the direction from the starting node to the selected node, as shown in Figure 4.16. After saving, edges will be formed between nodes, as shown in Figure 4.17. When the admin clicks the white node in the middle of the edge, a menu will be prompted, allowing the admin to choose to delete the edge or enter the distance of the edge.

4.3.7 Manage Nodes

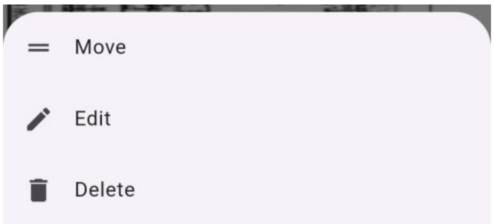


Figure 4.19 Menu for a node

A menu will be prompted when the admin selects a node, which allows the admin to:

- Move or delete the selected node
- Edit the selected node information. It will direct the admin to the page shown in Figure 4.13 to modify the information or download the ArUco marker of the node.

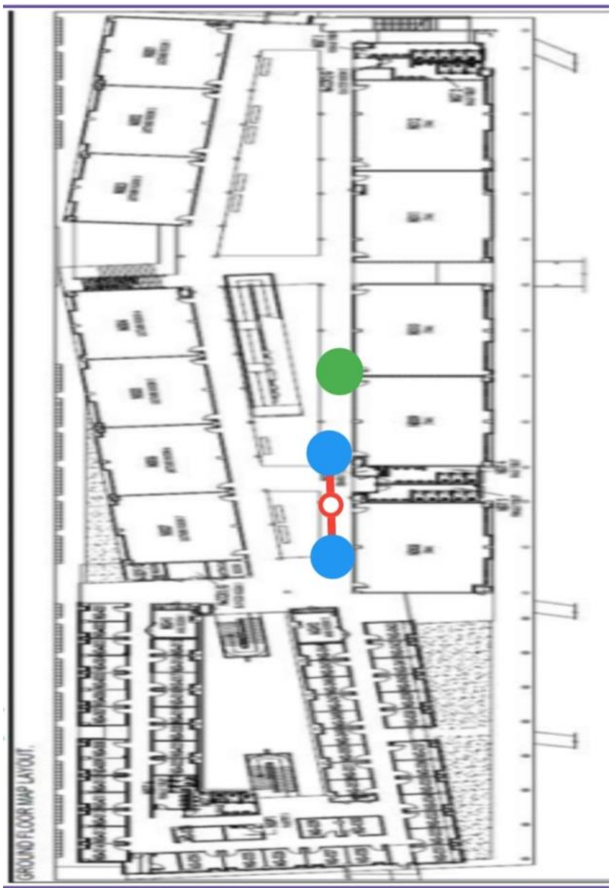


Figure 4.20 Move and resize the node

When the admin selects Move, the node turns green, allowing it to move and resize. This can also be done by long-pressing the node. However, this function will be disabled only if a node is connected to an edge.

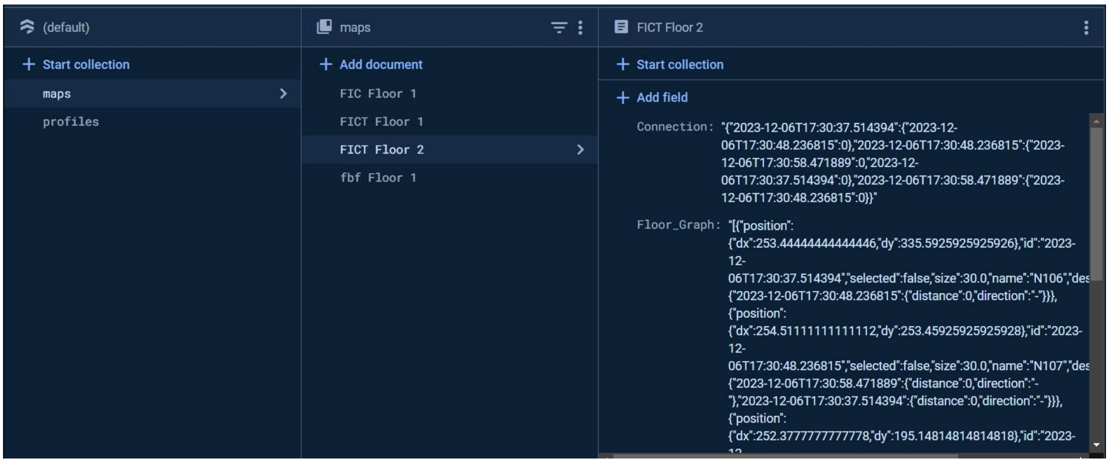


Figure 4.21 The floor graph and connection stored in Cloud Firestore

After the admin exits the floor graph page or switches to another floor, it will store the floor graph and connections in the Cloud Firestore.

Chapter 5

System Evaluation and Discussion

This chapter will discuss the setup and the result of two evaluations that have been done in this project, which are comprehensive evaluation on ArUco markers and QR codes, and pilot testing. Then, it will evaluate the project objective and the project challenges.

5.1 Comprehensive Evaluation of ArUco Markers and QR Codes

The previous version of the system used a QR code for localization, but its performance was not so good. Therefore, the current system replaces the QR code with the ArUco marker. In order to determine whether the performance of the current system has improved, we will compare the performance of the ArUco marker and QR code in terms of distance and angle. In addition, we will also evaluate the accuracy of both marker detections using a confusion matrix.

5.1.1 Evaluation Setup

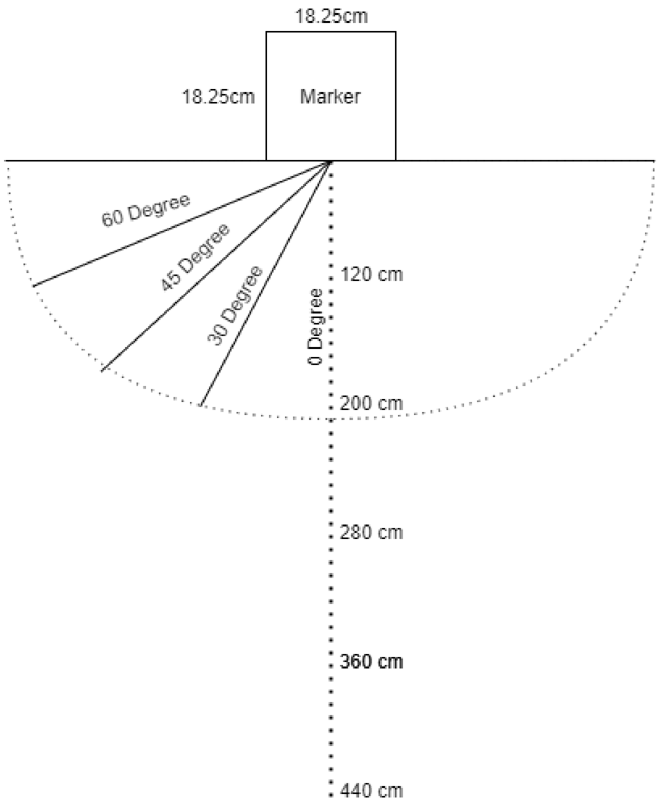


Figure 5.1 Setup for Performance Comparison

As shown in Figure 5.1, we define 5 distances and 4 angles for performance comparison. When conducting tests at different distances, we maintained a fixed angle of 0 degrees. Conversely, when testing at different angles, we ensured a fixed distance of 200 cm. We prepared 5 different ArUco markers and 5 different QR codes with the size of 18.25 cm x 18.25cm. Then, we place all the markers in different backgrounds and take multiple images, such as normal background, chaotic background, low light background, and over-bright background. Therefore, each setting will have 20 images. For instance, 20 images are captured to test the performance of all five different ArUco in a distance of 120cm with four different backgrounds.

For the confusion matrix, 10 samples are prepared to test the ArUco marker detector and QR code detector. The samples include 3 DICT_ARUCO_ORIGINAL ArUco markers, 3 QR codes, a DICT_4x4_250 ArUco marker, a 16h5 AprilTag, a chessboard, and a ChArUco diamond marker.

5.1.2 Performance Comparison

In this section, we will compare the performance of the ArUco marker and QR code at different distances and angles. As mentioned before, each setting will have 20 images input to both detectors. Then, the total time taken to detect all images will be averaged, and the number of success cases will be recorded.

Distance (cm)	Average Time (milliseconds)		Success Rate (%)	
	ArUco Marker	QR Code	ArUco Marker	QR Code
120	28.5	473.2	100	60
200	33.2	348.6	100	40
280	34.3	312.3	90	0
360	35.1	180.3	80	0
440	36.7	178.8	40	0

Table 5.1 Performance comparison in terms of distance

From the result in Table 5.1, it is obvious that the ArUco marker performs better than the QR code in terms of distance. Based on the average time, we can interpret that the ArUco marker can be more easily detected than the QR code. However, the average time of the QR code keeps decreasing when further distance. This is because the QR code detector fails to detect the QR code.

Before the distance of 200 cm, the ArUco marker can achieve a 100% high success rate, while the QR code achieves a lower success rate. After the distance of 200 cm, the success rate of the ArUco marker started to decrease but still maintained a high success rate in the distances of 280 cm and 360 cm. On the other hand, the QR code detector fails to detect any QR code after 200 cm, thus it achieves a 0% success rate. Therefore, the ArUco marker performs well before the distance of 280 cm, while the QR code does not perform well in any distance mentioned in the table.

Angle (Degree)	Average Time (milliseconds)		Success Rate (%)	
	ArUco Marker	QR Code	ArUco Marker	QR Code
0	33.2	348.6	100	40
30	34.8	245.3	100	30
45	36.3	183.3	100	0
60	41.7	142.8	80	0

Table 5.2 Performance comparison in terms of angle

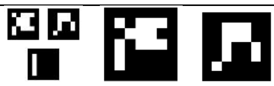
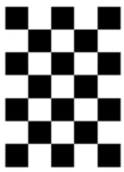
Besides distance, the ArUco marker also performs better than the QR code in terms of angles, as shown in Table 5.2. Based on the average time, the detector took around 35 milliseconds to detect the ArUco marker between 0 to 45 degrees, which is better than the QR code. However, at 60 degrees, the detector took a much longer time to detect the ArUco marker compared with different angles and distances. This may be influenced by different backgrounds like low lighting background, which makes it difficult for the detector to find the marker corner.

Based on the success rate, the ArUco marker can achieve a high success rate in all angles, which is 80% or above. While QR code only works before 30 degrees, and the success rate is lower than 50%. Therefore, the ArUco marker performs well in any angle mentioned in the table, while the QR code does not perform well in any angle mentioned in the table.

5.1.3 Confusion Matrix

As mentioned before, there are 10 samples prepared for the confusion matrix to evaluate the accuracy of the ArUco marker detector and QR code detection. There are three true samples for the ArUco marker detector, which are DICT_ARUCO_ORIGINAL ArUco markers. Same as the evaluation for the QR code detector, it has three QR codes as true samples.

As shown in Tables 5.3 and 5.4, both detectors achieve 100% accuracy, which means the detectors are capable of differentiating true and false samples correctly. Especially the ArUco marker detector can determine the correct type of ArUco markers even if they look very similar. For instance, false samples like DICT_4x4_250 ArUco marker and AprilTag 16h5 do not confuse the detector to detect wrongly. Thus, both detectors are reliable and practical to use in real scenarios.

Detected / Actual	True	False
True	 (3 x DICT_ARUCO_ORIGINAL ArUco markers)	-
False	-	(3 x QR codes)  (DICT_4x4_250 ArUco marker)  (AprilTag 16h5)  (ChessBoard)

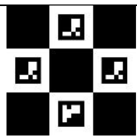
		 (ChArUco Diamond)

Table 5.3 Confusion matrix for ArUco marker

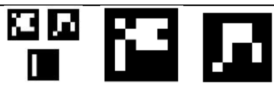
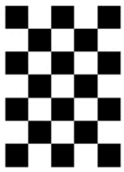
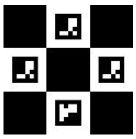
Actual \ Detected	True	False
True	(3 x QR codes)	-
False	-	 (3 x ArUco markers)  (DICT_4x4_250 ArUco marker)  (AprilTag 16h5)  (ChessBoard)  (ChArUco Diamond)

Table 5.4 Confusion matrix for QR code

5.2 Pilot testing

Pilot testing allows to test the system with a small number of participants in real-case scenarios. Therefore, we can understand the potential of the project before spending more time and determine whether the project is feasible and worth continuing. The testing will be held on the first floor of UTAR block N, and 5 students will be represented as blind students navigating around the testing venue.

There are two components to measure in this testing, which are effectiveness and satisfaction. Effectiveness measures the total number of completed paths and errors from all participants. Satisfaction measures the quality of interaction between the participants and the application. To measure these two components, a demonstration will be done to evaluate the effectiveness, then a questionnaire will be done after the demonstration to evaluate the satisfaction.

5.2.1 Demonstration Setup

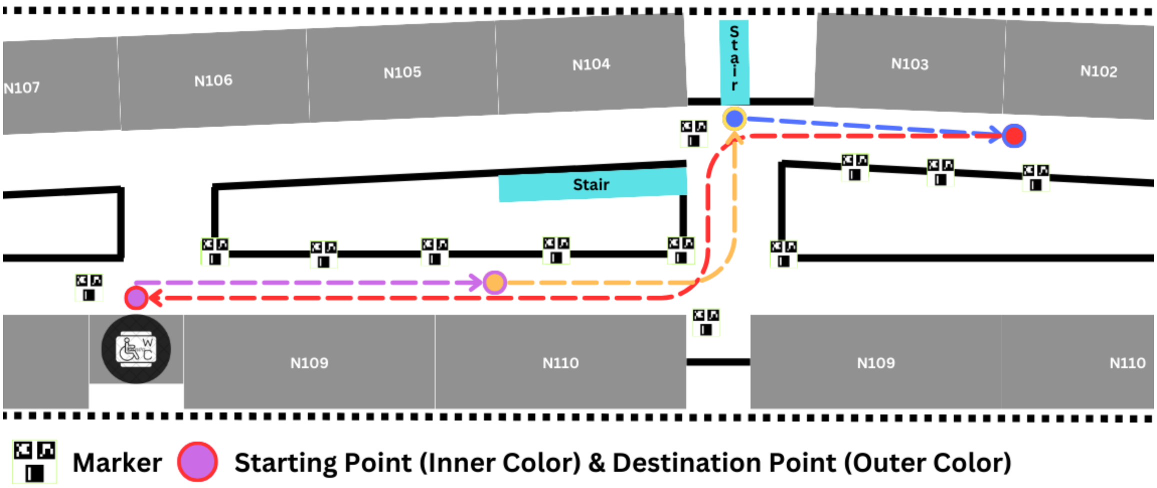


Figure 5.2 Demonstration path

As shown in Figure 5.2, we designed a real scene with four paths, which are located on the first floor of the UTAR block N. A blind student is taking a class in the N102 classroom (blue path). After class, he needs to go to the bathroom (red path) before the practice class in the N110 lab (purple path). He will go home after the practice class (yellow path). These paths are designed to include different situations, such as straight paths, bi-directional paths, and paths with turning points. In addition, there are no obstacles in all paths, because our application does not handle obstacles. Then, we prepared 12 markers along the path, and some markers were single-sided, double-sided, or three-sided. Thus, the marker can be detected in different directions.

Before starting the demonstration, we will provide participants with clear instructions on how the demonstration works and the use of application features. Since we are testing from blind people's perspective, all participants will be blindfolded, and we will follow them all the way to prevent any accidents. In addition, we will not interfere in demonstrations, but only when the participants ask for help.

To evaluate the effectiveness, we will count the number of participants completed in each path and the number of errors they made in each path. As far as completion is concerned, a participant's successful navigation from the starting point to the destination will be counted as completion. As far as errors are concerned, if participants give up on finishing the path or ask for help, they are counted as errors.

5.2.2 Questionnaire Setup

After the demonstration, a questionnaire will be distributed to all participants via Google Forms to measure their satisfaction. As shown in the Appendix, the questionnaire has 27 questions that include multiple-choice questions, open-ended questions, and rating scale questions. First, it will ask for simple demographic information, including age, gender, faculty studied, and level of education. Then, the questionnaire will ask some general questions to understand the participant's perspective on indoor navigation applications. In order to evaluate the satisfaction of the system, we break into 5 scales, which are:

- Usefulness: assess how well the application helps users achieve their goals.
- Efficiency: assess how much effort users feel they need to achieve their goals and how responsive the application is to their actions.
- Dependability: assess whether users feel in control of the application, and determine the reliability of the application in real scenes.
- Quality of audio guidance: assess the quality and reliability of the guidance content
- Usability: understand how well the application interacts with the user.

5.2.3 Demonstration Evaluation

Path	Completion	Error
Path 1	5	1

Path 2	5	3
Path 3	5	0
Path 4	5	1
Total	20	5

Table 5.5 Completion and error of demonstration

Table 5.5 shows the number of participants who completed each path and the number of errors they made in each path. Based on the result, the system is quite effective since all participants can complete all the paths. However, the number of participants is not sufficient, it is difficult to prove that this system is completely effective.

Besides that, there are 4 errors made during the demonstration. However, these errors are recoverable, which means the participant still can complete the path even error occurred. These errors are identified:

- Aggressive movement: the participant walks too fast or waves the phone aggressively, which causes the camera unable to detect the marker properly.
- Veering: the participant deviates from the path and drifts to one side. This can easily happen when the navigation path is long, such as path 2.

During the demonstration, most of the participants were very anxious since they had not experienced as blind before. Thus, there were many errors in paths 1 and 2. Once the participants are familiar with the application and environment, the whole process of demonstration will be less struggle.

5.2.4 Questionnaire Evaluation

In the questionnaire, we received 5 respondents to evaluate the satisfaction by measuring the usefulness of the application, efficiency of the application, dependability of the application, quality of audio guidance of the application, and usability of the application.

5.2.4.1 Demographic and User perspective on Indoor Navigation Application

According to the demographic results of the questionnaire, most of the participants are FICT undergraduate students aged 22 to 24. Thus, most of them have a high level of technological knowledge and a high education level. Besides that, the majority did not use any indoor navigation application and had no difficulties navigating in a large indoor space. Hence, they are not familiar with this kind of application. However, all of them think that indoor navigation applications are very helpful for blind people. It is a good sign that our project is a benefit for blind people.

5.2.4.2 Usefulness of the Application

Based on the figure below, it shows that the majority think that the application is very useful for blind and visually impaired people. They found this application helpful because it provides clear guidance during the navigation, and it can ensure the user stays on track. Furthermore, all participants found the application to be highly beneficial to their navigation experience. It shows that the application can improve the user's ability to navigate indoor space effectively. In addition, the majority feel that the application sufficiently rewards them for using it.

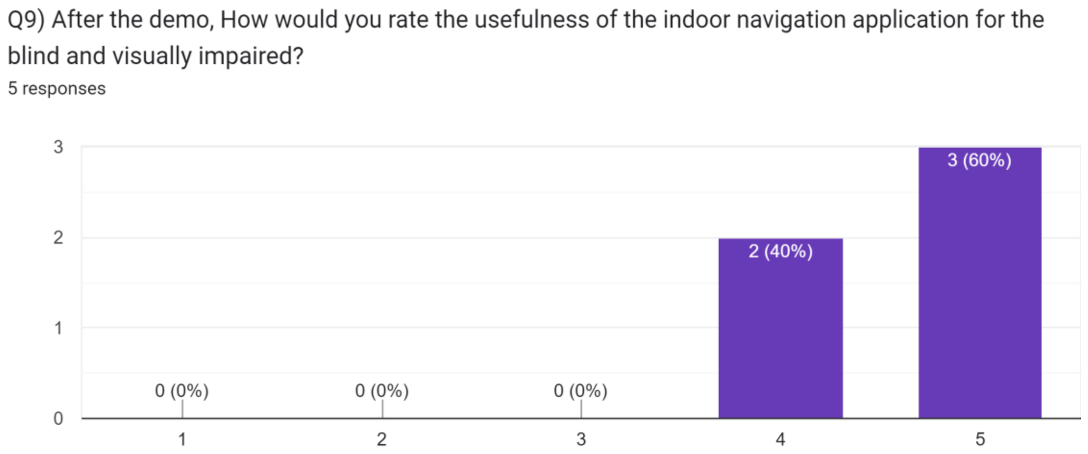


Figure 5.3 Indoor Navigation Application Usefulness Chart

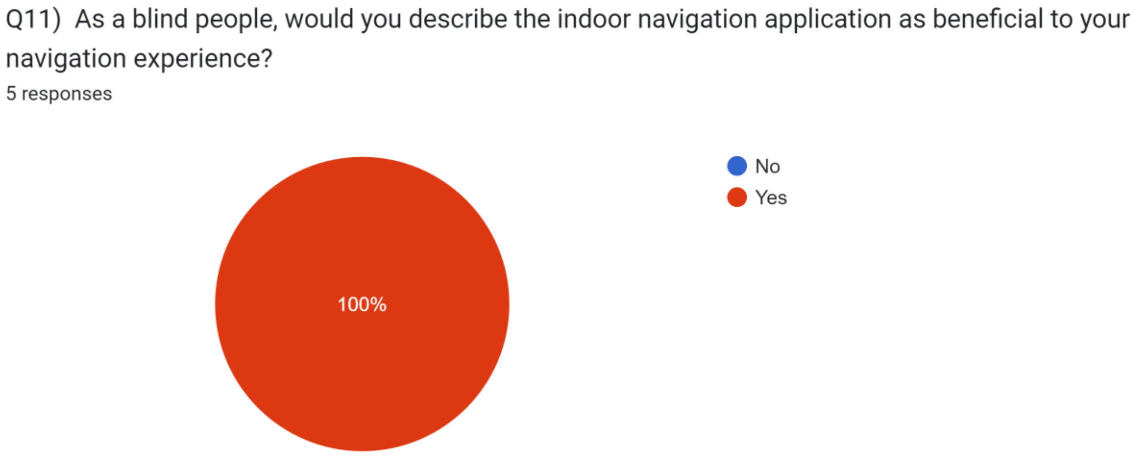


Figure 5.4 Indoor Navigation Application Beneficiary Chart

5.2.4.3 Efficiency of the Application

Based on the figure below, the majority agree that the application is efficient and practical for indoor navigation. 60% of respondents consider the speed of the application to be satisfactory, while the remaining respondents opt for a moderate rating. Therefore, the speed of the application needs to be improved in the future. Furthermore, all respondents concur that the application does not have unnecessary actions which indicates that its design is concise and efficient.

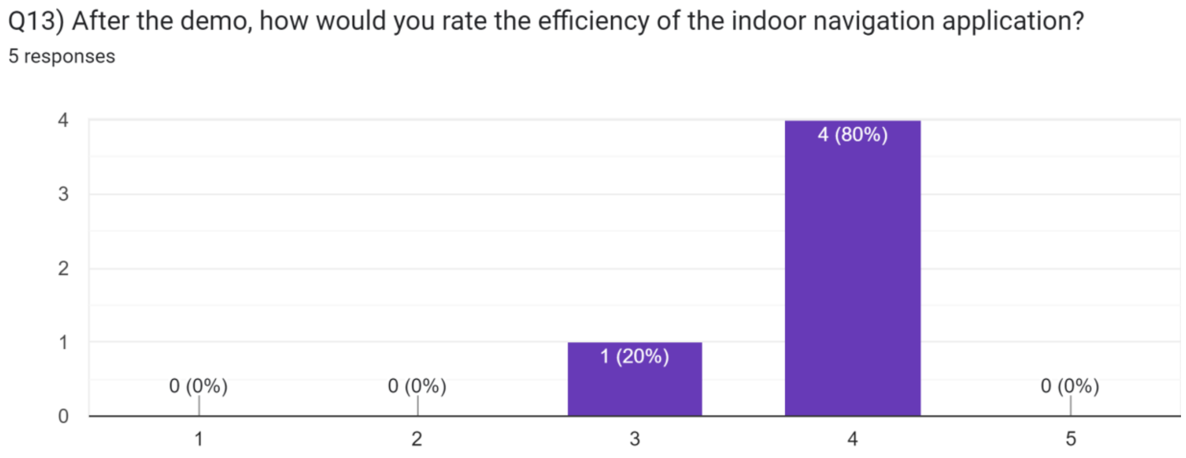


Figure 5.5 Indoor Navigation Application Efficiency Chart

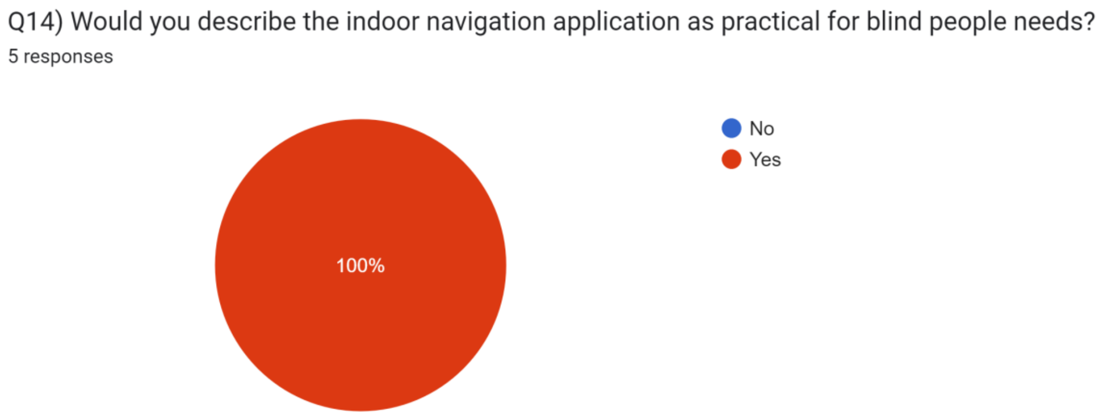


Figure 5.6 Indoor Navigation Application Feasibility Chart

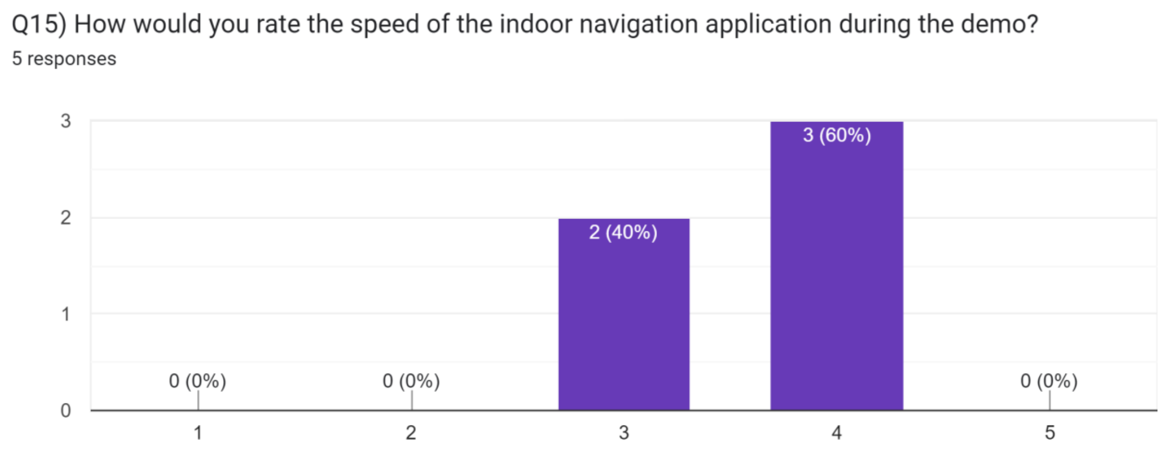


Figure 5.7 Indoor Navigation Application Speed Chart

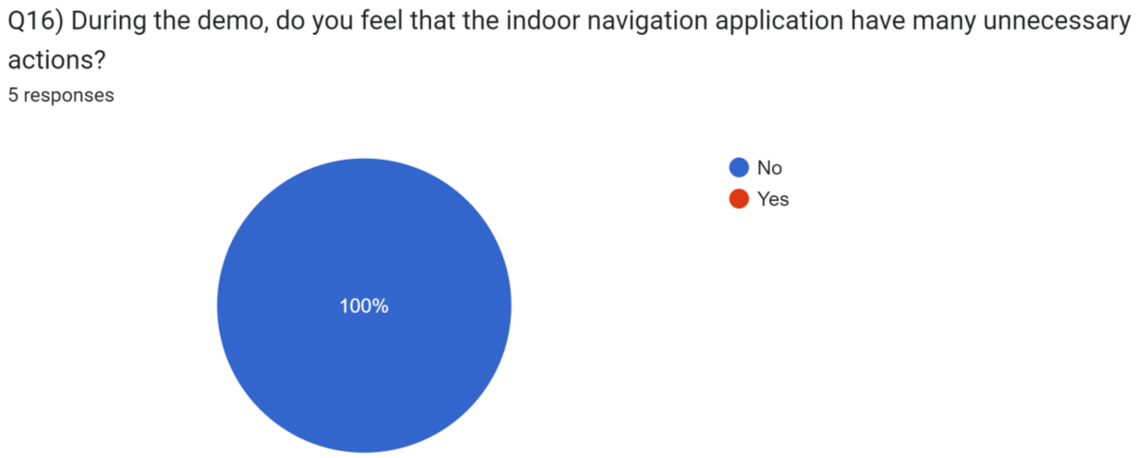


Figure 5.8 Indoor Navigation Application Unnecessary Action Chart

5.2.4.4 Dependability of the Application

The majority agree that the application is dependable, indicating a good level of trustworthiness and reliability. A good level of trustworthiness was gained in the demonstration. During the demonstration, the majority felt anxious at the beginning, but they started to feel confident after using the application a few times. However, the majority think the application is only safe for small and clear indoor spaces, which indicates the application does not have sufficient safety mechanisms like obstacle detection. Furthermore, the majority noted that the audio guidance and vibration assisted their navigation in the demonstration.

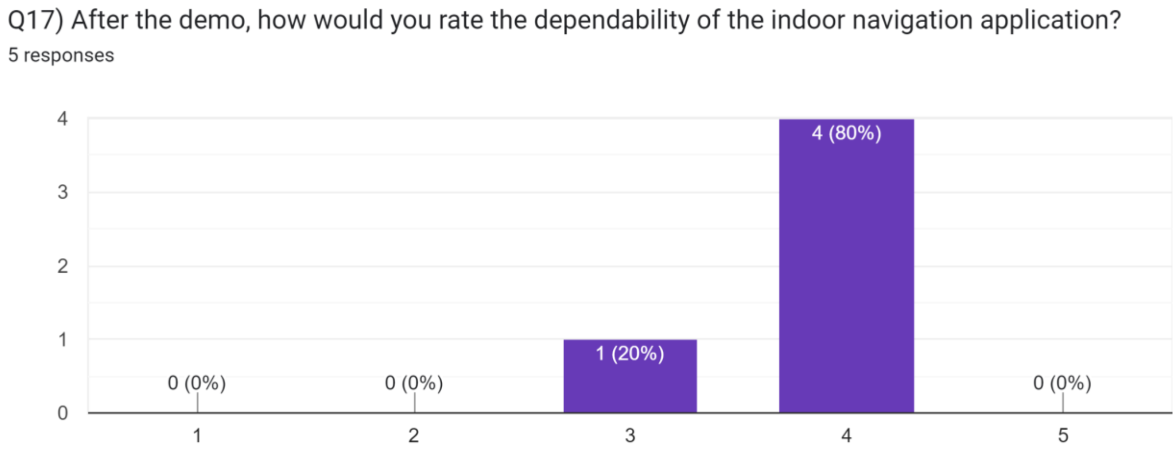


Figure 5.9 Indoor Navigation Application Dependability Chart

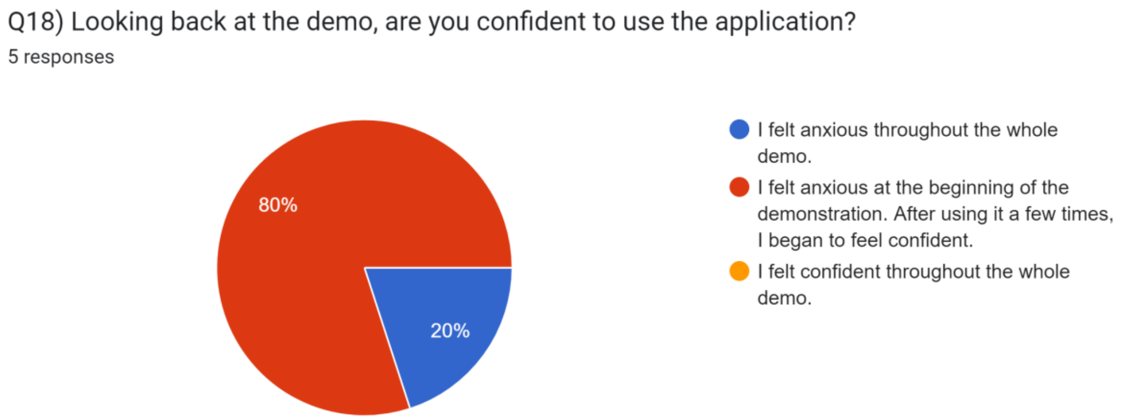


Figure 5.10 Indoor Navigation Application Confidence Chart

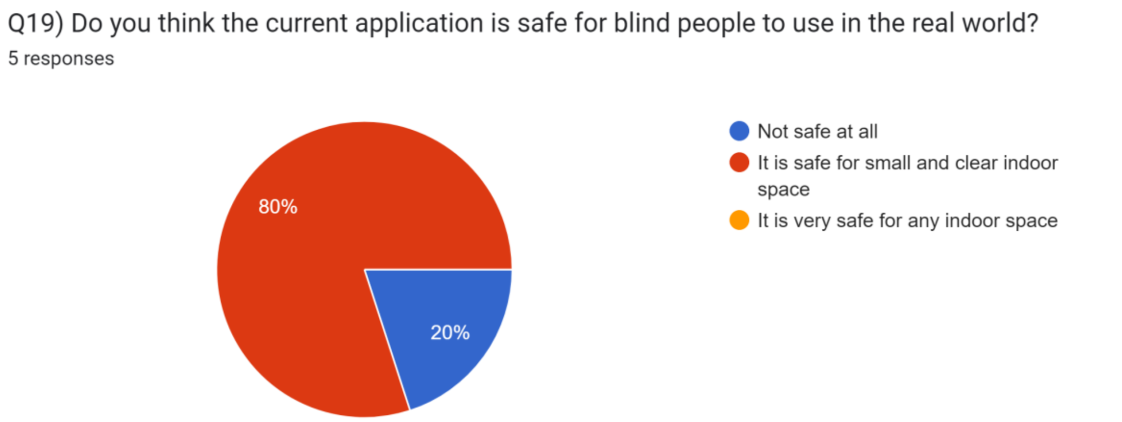


Figure 5.11 Indoor Navigation Application Blind People Safety Chart

5.2.4.5 Quality of the Audio Guidance

The majority think the content of the audio guidance provided is very trustworthy and accurate, which shows that the guidance information is reliable. Besides that, all respondents can easily follow the content of the audio guidance during the demonstration. In addition, all respondents agree that the guidance is extremely helpful during the demonstration. Therefore, the result indicate that the audio guidance is sufficiently good and necessary for blind people

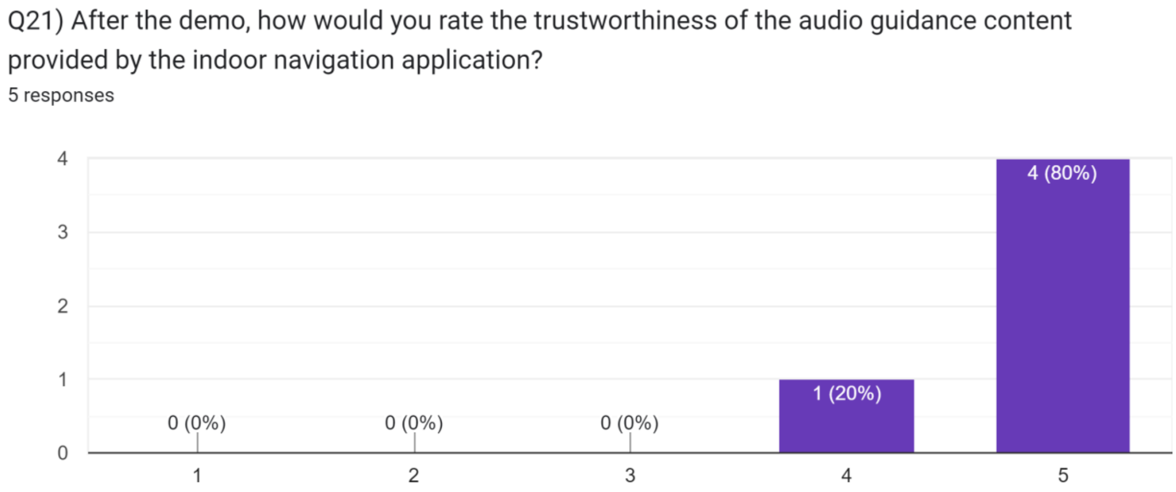


Figure 5.12 Trustworthiness of Audio Guidance Content Chart

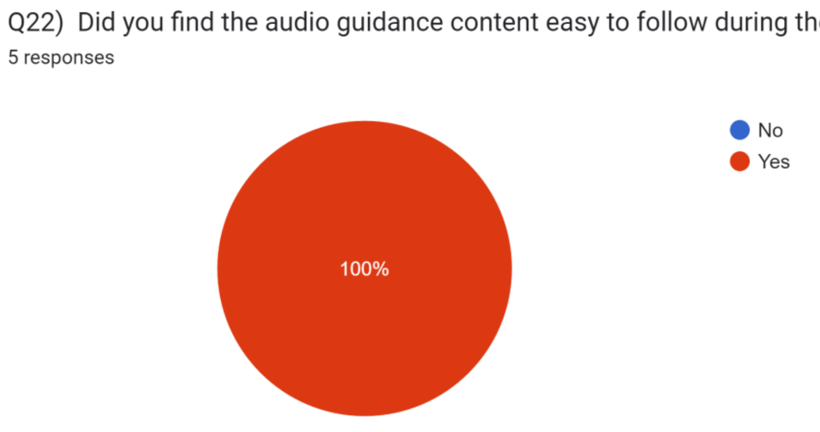


Figure 5.13 Audio Guidance Content Ease to Follow Chart

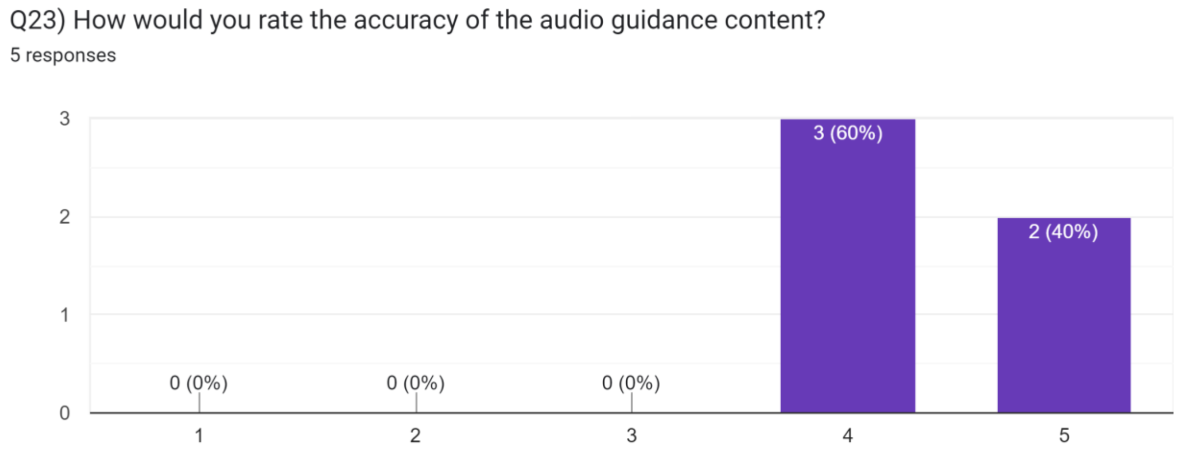


Figure 5.14 Audio Guidance Content Accuracy Chart

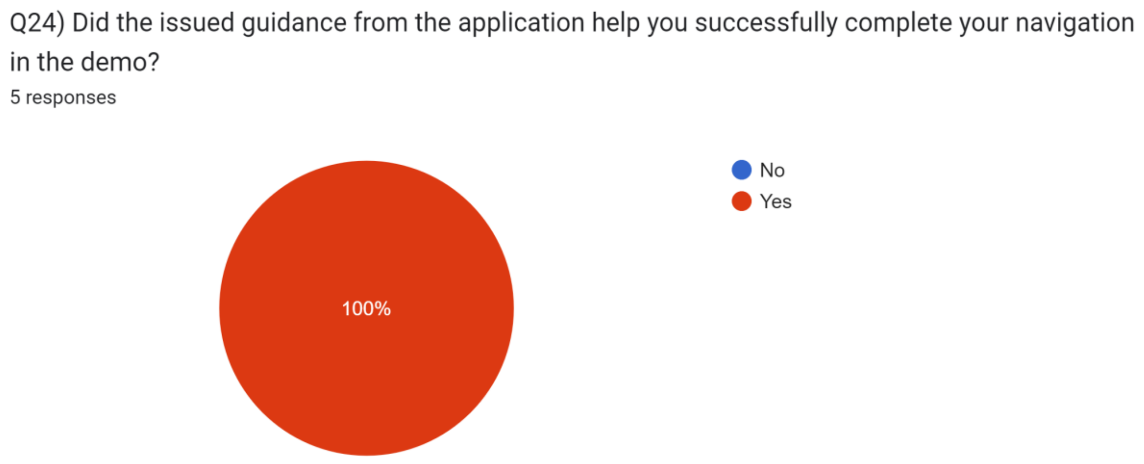


Figure 5.15 Audio Guidance Content Success in Navigation Chart

5.2.4.6 Usability of the Application

Given that the majority of respondents find the application highly user-friendly for blind individuals. Besides that, all respondents agree that the application is well-structured and easy to learn for blind people, it can be confidently inferred that the application provides an intuitive and accessible experience for blind users, enhancing their ability to navigate effectively.

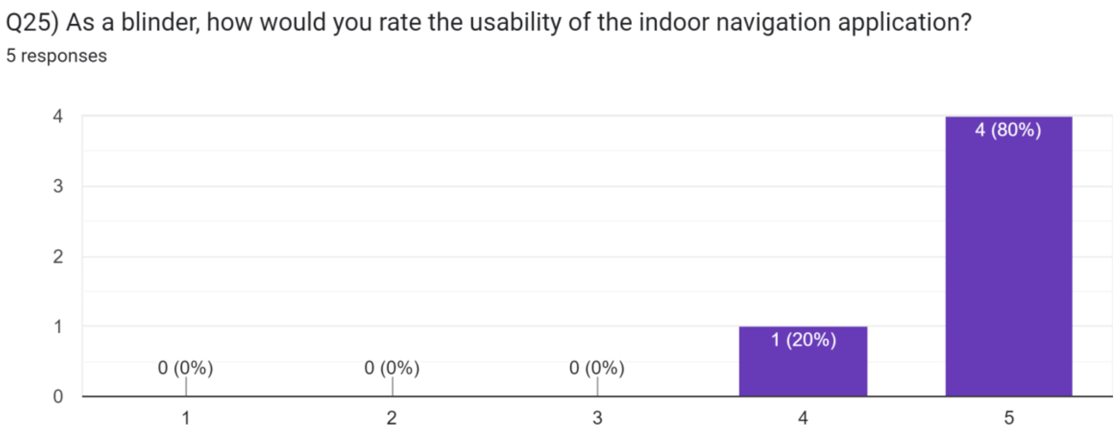


Figure 5.16 Indoor Navigation Application Usability Chart

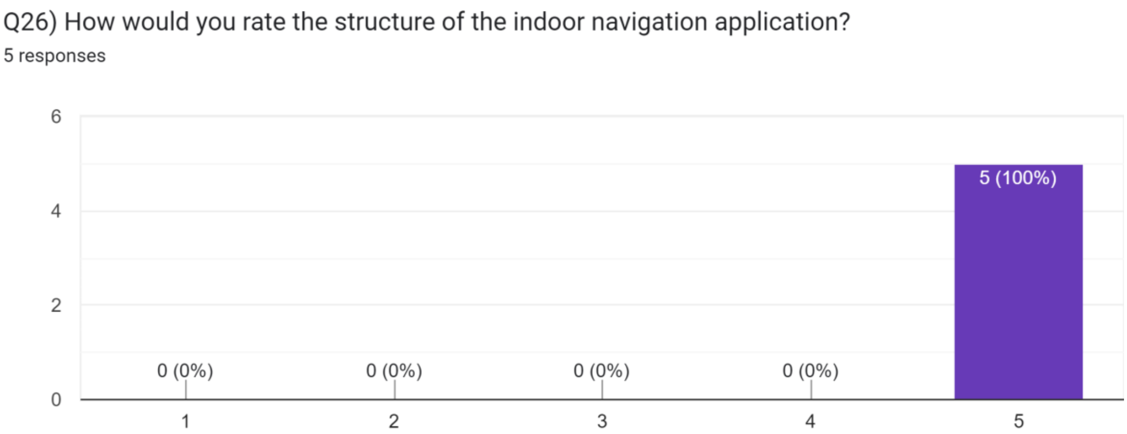


Figure 5.17 Indoor Navigation Application Structure Chart

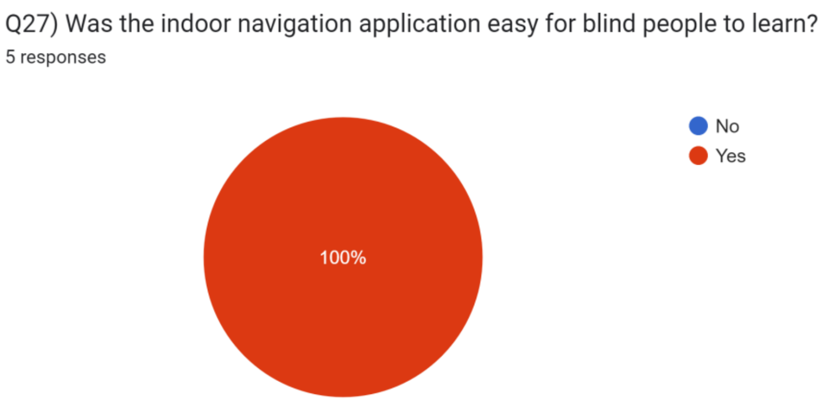


Figure 5.18 Indoor Navigation Application Ease to Learn Chart

5.3 Objectives Evaluation

Table 5.6 evaluates the project objective by determining whether the output of the main functions fulfills all the objectives.

Function	Expected Output	Comment
Mapping Module		
Manage building profile	Can add, edit, and delete building profile	Done
Create floor graph	Can add nodes and edges, and insert necessary information	Done
Modify floor graph	Can edit the information of nodes and edges and move nodes.	Done
Generate Marker	Can generate unique ArUco marker and download it	Done
Authentication	Can verify the admin account	Done
Localization Module		
Marker Detection	Able to detect the marker at different angles and distances in real time.	Done
Position Estimation	Able to identify the current position of the user	Done
Navigation Module		
Generate shortest path	Able to generate the shortest path based on the distance that the admin inserted	Done

Generate audio guidance	Able to provide clear audio guidance using text-to-speech tool	Done
Ensure the user moving in the correct direction	Compass and vibration are implemented to guide the user to move in the correct direction	Done

Table 5.6 Evaluation of Project Objectives

5.4 Discussion on System Evaluation

In this project, we have performed a comprehensive evaluation of ArUco markers and QR codes, and pilot testing to assess the effectiveness and satisfaction of the system. For a comprehensive evaluation of ArUco markers and QR codes, it is obvious that ArUco markers perform better than QR codes in terms of distances and angles. For pilot testing, most participants managed to complete the whole demonstration. In addition, the majority very satisfy the usefulness and usability of the application and the quality of the audio guidance content. The efficiency and dependability of the application also receive some positive feedback but still have space for improvement.

However, there are several challenges when performing both evaluations. For a comprehensive evaluation of ArUco markers and QR codes, the number of samples is not sufficient, even though each setting took 20 images. Besides that, the coverage to examine the performance between ArUco markers and QR codes can be improved, such as different resolutions of markers and backgrounds with different brightness.

For the pilot testing, it tests the system with a small number of participants, which is insufficient. In order to get more effective and better results, we should collect more feedback from a larger group of participants, so that the test results will be more detailed and accurate. In addition, the demonstration can achieve better results in a larger venue that has tactile paving and more consideration of the path. In addition, when the target participants are legally blind, the test results will be better, so the test results will be more convincing and comprehensive.

Chapter 6
Conclusion

In conclusion, our project aims to develop a mobile-based indoor navigation system using markers to assist users in navigating complex indoor environments, particularly blind people. The project focuses on mapping, localization, and navigation.

Based on the current work, the system can build different floor graphs for different buildings. Thus, it can accommodate any changes in the indoor environment. Besides that, it can identify the user's position when the system detects a marker. In addition, it can generate the shortest path based on the distance and the selected destination. During the navigation, both audio guidance and vibration are utilized to ensure that the user moves in the correct direction. Hence, we have successfully done mapping, localization, and navigation, but it still has the potential for improvement in the future.

For our evaluation, we found that the ArUco marker performs better than the QR code, thus our application will implement the ArUco marker. Besides that, the application is quite effective since a small group of people manages to navigate in a small indoor space using the application. In addition, the application is quite satisfying in terms of the usefulness and usability of the application and the quality of the audio guidance.

Even though our main target audience is blind people, we can expand our system's target audience by implementing visual guidance via AR in the future. Thus, our system is suitable for both blind and normal users. Besides implementation, we should extend the system evaluation to achieve more convincing and comprehensive results, such that the system will be more practical, efficient, and secure for the real world.

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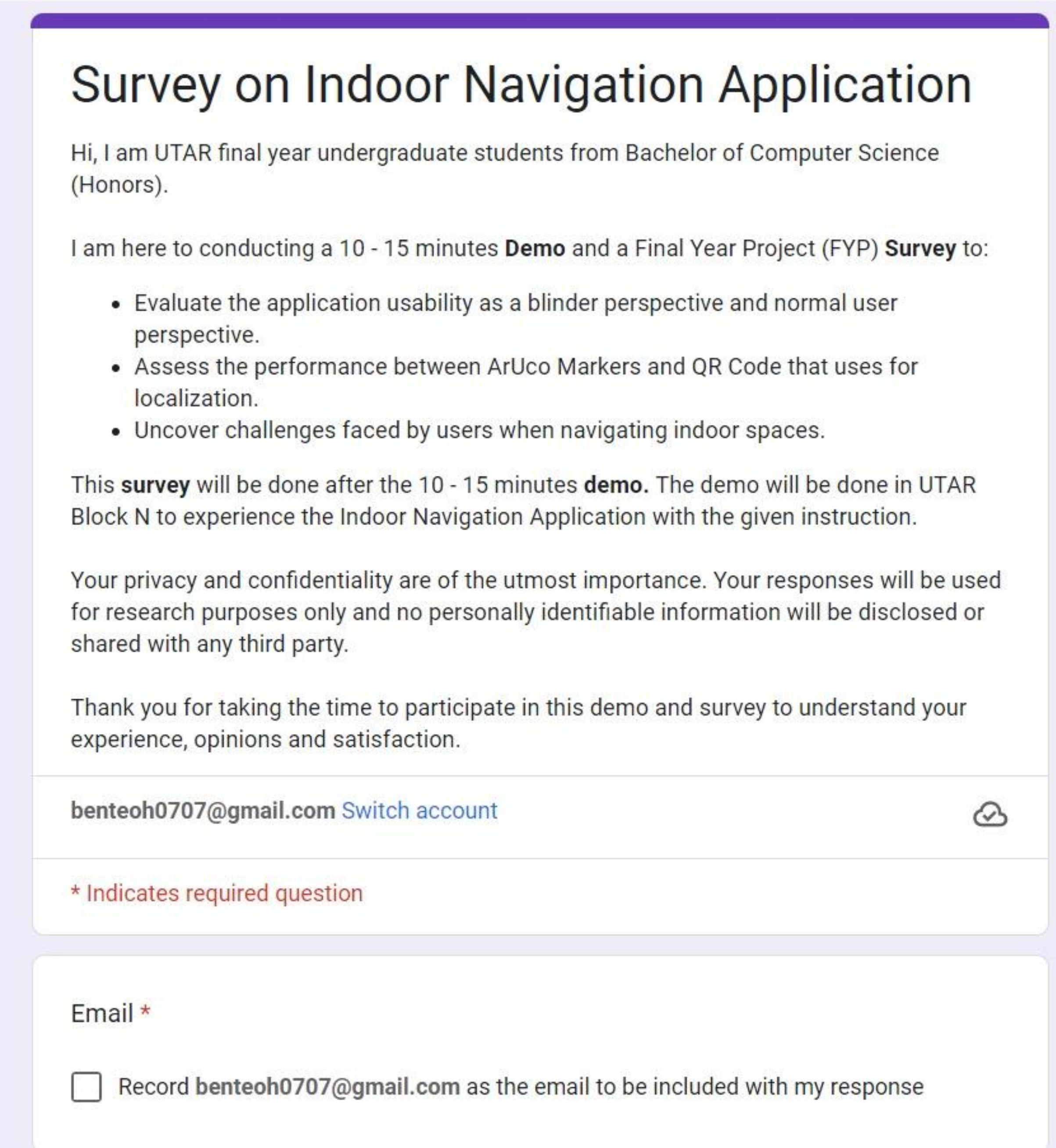
APPENDIX



Survey on Indoor Navigation Application

Hi, I am UTAR final year undergraduate students from Bachelor of Computer Science (Honors).

I am here to conducting a 10 - 15 minutes **Demo** and a Final Year Project (FYP) **Survey** to:

- Evaluate the application usability as a blinder perspective and normal user perspective.
- Assess the performance between ArUco Markers and QR Code that uses for localization.
- Uncover challenges faced by users when navigating indoor spaces.

This **survey** will be done after the 10 - 15 minutes **demo.** The demo will be done in UTAR Block N to experience the Indoor Navigation Application with the given instruction.

Your privacy and confidentiality are of the utmost importance. Your responses will be used for research purposes only and no personally identifiable information will be disclosed or shared with any third party.

Thank you for taking the time to participate in this demo and survey to understand your experience, opinions and satisfaction.

benteoh0707@gmail.com Switch account

* Indicates required question

Email *

☐ Record **benteoh0707@gmail.com** as the email to be included with my response

Demographic

Q1) Age *

- ◯ 18 - 21 years old
- ◯ 22 - 24 years old
- ◯ 25 years old - above

Q2) Gender *

- ◯ Male
- ◯ Female

Q3) Faculty *

- ◯ FICT
- ◯ FBF
- ◯ FAS
- ◯ Other: ____________________

Q4) Level of Education *

- ◯ Undergraduate
- ◯ Postgraduate
- ◯ Other: ____________________

Section 2 of 7

User perspective on Indoor Navigation Application

In this section, It gathers the user view and past experiences on Indoor Navigation Application to identify the usefulness of indoor navigation.

Q5) Did you use any indoor navigation application before? *

- Yes
- No

Q6) If yes, what is the application name?

Short-answer text

Q7) Did you experience difficulties to reach your destination in a large indoor space like shopping malls or airports? *

- Never
- Rarely
- Frequently

Q8) How do you think Indoor Navigation application is helpful for **blinder**? *

- Not helpful at all
- Completely helpful

Section 3 of 7

Usefulness of the Application

This section evaluate how well does the indoor navigation application helps users achieve their goals.

Q9) After the demo, How would you rate the usefulness of the indoor navigation application for the blind and visually impaired? *

	1	2	3	4	5	
Not Useful at all	○	○	○	○	○	Extremely useful

Q10) In what ways did you find the indoor navigation application helpful

Long-answer text

Q11) As a blind people, would you describe the indoor navigation application as beneficial to your navigation experience? *

- ○ No
- ○ Yes

Q12) After the demo, do you feel that the indoor navigation system sufficiently rewards you for using it? *

- ○ No
- ○ Yes

Section 4 of 7

Efficiency of the Application

This section assesses how much effort users feel they need to achieve their goals and how responsive the application is to their actions.

Q13) After the demo, how would you rate the efficiency of the indoor navigation application?

	1	2	3	4	5	
Not efficient at all	○	○	○	○	○	Extremely efficient

Q14) Would you describe the indoor navigation application as practical for blind people needs?

○ No

○ Yes

Q15) How would you rate the speed of the indoor navigation application during the demo?

	1	2	3	4	5	
Very slow	○	○	○	○	○	Very fast

Q16) During the demo, do you feel that the indoor navigation application have many unnecessary actions?

○ No

○ Yes

Section 5 of 7

Dependability of the Application

This section measures whether users feel in control of the application, and determines the reliability of the application in real scenes from the user's point of view.

Q17) After the demo, how would you rate the dependability of the indoor navigation application?

	1	2	3	4	5	
Not dependable at all	○	○	○	○	○	Extremely dependable

Q18) Looking back at the demo, are you confident to use the application? *

- ○ I felt anxious throughout the whole demo.
- ○ I felt anxious at the beginning of the demonstration. After using it a few times, I began to feel confident.
- ○ I felt confident throughout the whole demo.

Q19) Do you think the current application is safe for blind people to use in the real world? *

- ○ Not safe at all
- ○ It is safe for small and clear indoor space
- ○ It is very safe for any indoor space

Q20) In what ways did the indoor navigation application support your navigation in the demonstration?

Long-answer text

Section 6 of 7

Quality of the Audio Guidance

This section evaluate the quality and reliability of the guidance's' content

Q21) After the demo, how would you rate the trustworthiness of the audio guidance content provided by the indoor navigation application? *

	1	2	3	4	5	
Not trustworthy at all	○	○	○	○	○	Extremely trustworthy

Q22) Did you find the audio guidance content easy to follow during the demo? *

- ○ No
- ○ Yes

Q23) How would you rate the accuracy of the audio guidance content? *

	1	2	3	4	5	
Not accurate	○	○	○	○	○	Extremely accurate

Q24) Did the issued guidance from the application help you successfully complete your navigation in the demo? *

- ○ No
- ○ Yes

Section 7 of 7

Usability of the Application

This section determines the usability of the application to understand how well the application interacts with the user.

Q25) As a **blinder**, how would you rate the usability of the indoor navigation application? *

	1	2	3	4	5	
Not user friendly at all	○	○	○	○	○	Extreme user friendly

Q26) How would you rate the structure of the indoor navigation application?

	1	2	3	4	5	
Unclear	○	○	○	○	○	Very clear

Q27) Was the indoor navigation application easy for blind people to learn? *

- ○ No
- ○ Yes

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Y3S3	**Study week no.: 6**
Student Name & ID: Teoh Zhen Quan 21ACB01805	
Supervisor: Ts Dr Tan Hung Khoon	
Project Title: A Smart Marker-based Indoor Navigation System	

1. WORK DONE

[Please write the details of the work done in the last fortnight.]

Successfully create the ArUco detector

2. WORK TO BE DONE

- **Integrate the detector to the application**
- **Test the performance of the detector**
- **Pilot testing**

3. PROBLEMS ENCOUNTERED

No problem

4. SELF EVALUATION OF THE PROGRESS

The current development progress is under control.

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Y3S3	**Study week no.: 8**
Student Name & ID: Teoh Zhen Quan 21ACB01805	
Supervisor: Ts Dr Tan Hung Khoon	
Project Title: A Smart Marker-based Indoor Navigation System	

1. WORK DONE [Please write the details of the work done in the last fortnight.] Integrated the detector to the application
2. WORK TO BE DONE - **Test the performance of the detector** - **Pilot testing**
3. PROBLEMS ENCOUNTERED **No problem**
4. SELF EVALUATION OF THE PROGRESS **The current development progress is under control.**

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Y3S3	**Study week no.: 10**
Student Name & ID: Teoh Zhen Quan 21ACB01805	
Supervisor: Ts Dr Tan Hung Khoon	
Project Title: A Smart Marker-based Indoor Navigation System	

1. WORK DONE [Please write the details of the work done in the last fortnight.] Test the performance of the detector
2. WORK TO BE DONE - **Pilot testing**
3. PROBLEMS ENCOUNTERED **No problem**
4. SELF EVALUATION OF THE PROGRESS **The current development progress is under control.**

Supervisor's signature

Student's signature

FINAL YEAR PROJECT WEEKLY REPORT

(Project II)

Trimester, Year: Y3S3	**Study week no.: 12**
Student Name & ID: Teoh Zhen Quan 21ACB01805	
Supervisor: Ts Dr Tan Hung Khoon	
Project Title: A Smart Marker-based Indoor Navigation System	

1. WORK DONE [Please write the details of the work done in the last fortnight.] Perform pilot testing
2. WORK TO BE DONE - **Finish report writing**
3. PROBLEMS ENCOUNTERED **No problem**
4. SELF EVALUATION OF THE PROGRESS **The current development progress is under control.**

Supervisor's signature

Student's signature

POSTER

UNIVERSITI TUNKU ABDUL RAHMAN

Faculty of Information and Communication Technology

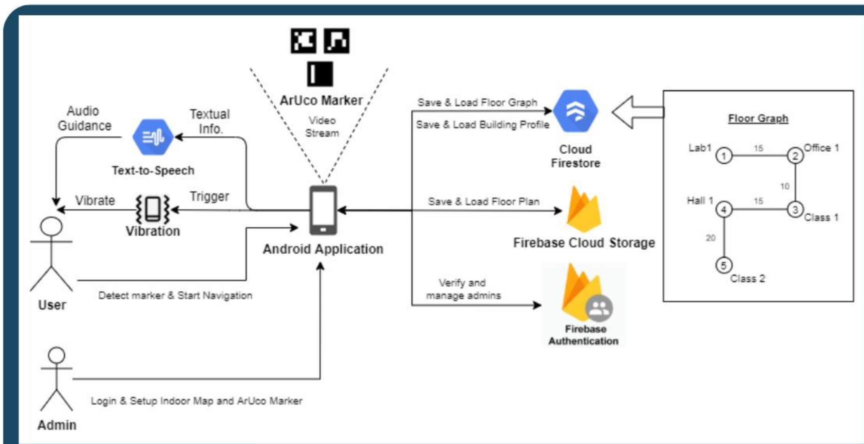
A Smart Marker-based Indoor Navigation System

Nowadays, The escalating trend in vision loss highlights the need for low-cost, user-friendly assistance devices. Among the challenges faced, indoor navigation emerges as a critical concern, particularly in navigating in complex spaces.

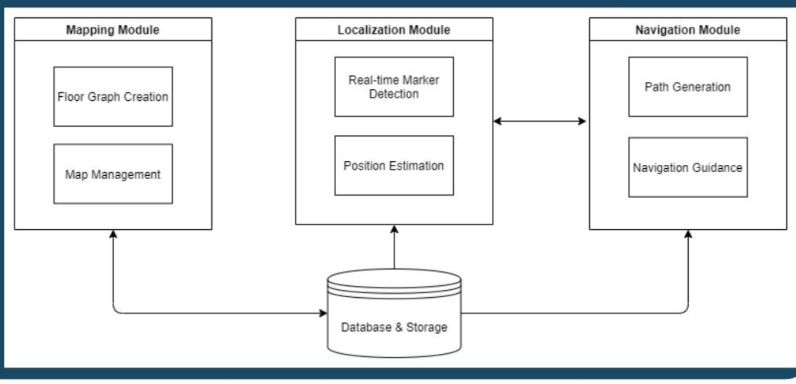
Objectives

- **To create and manage floor graphs for different buildings, and generate different markers.**
- **To provide accurate and real-time positioning in indoor space when scanning markers.**
- **To generate the shortest route, and provides guidance to users.**

System Overview



System Design



Candidate: TEOH ZHEN QUAN 21ACB01805

Supervisor: Ts Dr Tan Hung Khoon

APPENDIX

PLAGIARISM CHECK RESULT

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Full Name(s) of Candidate(s)	Teoh Zhen Quan
ID Number(s)	21ACB01805
Programme / Course	CS
Title of Final Year Project	A Smart Marker-based Indoor Navigation System

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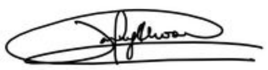

__________________	-
Signature of Supervisor	Signature of Co-Supervisor
Name: Tan Hung Khoon	Name: -
Date: 26 April 2024	Date: -

UNIVERSITI TUNKU ABDUL RAHMAN

FACULTY OF INFORMATION & COMMUNICATION TECHNOLOGY (KAMPAR CAMPUS)

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____

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