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A MIXED REALITY SOLUTION FOR INDOOR NAVIGATION

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Abstract

Indoor navigation technologies is a hot research topic in recent years. Different from outside navigation, this technology needs to consider building context, making indoor navigation system complex. Our research mainly focuses on finding a practical approach for indoor navigation. This solution needs to provide users who are in an indoor context with a navigation instruction system. We tested different approaches, and finally, the present approach is using a mixed reality solution to provide users with indoor navigation instructions. This solution needs to use Microsoft HoloLens to detect the indoor environment and provide indoor navigation guide information. HoloLens is an Augmented Reality helmet to provide user holograms that combine with environment context via Augmented Reality (AR) technology. The guide information will lead users from current positions to the positions which are desired by users. This navigation system can provide AR guidance for users in office buildings and other indoor environments to prevent users move their gaze from the forward direction to other places and focus on the indoor environment. The primary functionalities of our indoor navigation system are the deployment targets, the finding of target locations, generating pathways form current position to target location and provide users AR guide information and lead them to target locations.

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1

Introduction

Navigation is an approach for people to find ways in an unfamiliar environment to the target position. Modern navigation devices provide users with information that makes reference to reality and also monitors the movement of users. The crucial roles played by navigation is not only to understand the current location also bind the real world to maps to help users find their destination. The application of navigation is recently popular because of the considerable growth of commerce and tourism, and people have more possibilities to visit unfamiliar places.

1.1 Problems

There are some limitations of tradition navigation approaches that make navigation difficult.

1.1.1 Limitations of Traditional Maps

The traditional approach for visitors to understand environments is to provide them with useful guide pieces of information to find out the current position, and visitors can find a series of streets as pathways and go along these streets to arrive target location. A few years ago, when the modern navigation approaches were not accessible, visitors who visited a city they never came to before, needed to buy a paper map of this city in the train station or airport first. When the visitors want to go to a place, they only need to find the street nearby and also locate this street name on this map, and find the target position on the map they have, and find out directions to their targets and walk along the streets to the target position. This approach is also used in indoor scenarios. For example, museums post maps in some conspicuous places. These maps contain marks of current locations on the map to help visitors to find out current position, and these maps often mark the most desired places with some marks easily be found. Usually, a good map can help visitors to find their target location easily[1]. However, even a good map still cannot satisfy the need of all the visitors and shows the following limitations:

- Size limitation: Paper maps cannot provide all the details of a place. If tourists want to visit some of the less favourite places that are not marked on maps, usually these places are either not marked on maps or difficult to be found in maps because the markers are too small as the map from wvculture museum shows in Figure1.1 [2]. That means visitors need to spend too much time to find the target location by using paper maps and sometimes if the positions that be desired by users are not be marked, the time be wasted.

- Recognise limitation: Visitors have gaps in cognitive abilities. Some visitors can quickly recognise complex maps and even CAD graphs, but for some visitors it is challenging to recognise even simple maps. Moreover, if the map is not accurate, it will guide visitors to wrong positions. Map designers are always required to have very high skills in drawing and design abilities to make maps readable. Paper maps can make guide mistakes of either visitors or designers.

- Update limitation: Navigation systems need to make sure the target positions can always be found in maps. The paper map cannot update position information, that means visitors cannot use these maps to find the latest target position. When the target position has been changed, for example, a famous restaurant moved to another place, the visitors cannot find this restaurant with old maps. Moreover, making the paper map update is not easy, the publishing houses need to print the latest maps and replace the old version which already exists in the market, which wasted time and human power.

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[1] urlhttp://www.wwu.edu/huxley/spatial/tut/ALLGOODMAPS.pdf

[2] http://www.wvculture.org/museum/museum-map.html

Figure 1.1: Map with small markers from vwculture museum

1.1.2 Limitations of Satellite Positioning Systems

Taking the disadvantage of traditional paper map navigation, people need a new solution to find current position and target positions easily. There is one approach based on the technology of satellites navigation which calculates the distances between users and satellites to get user current location and provide them with navigation information.

There are four major satellite positioning systems, the United States GPS system, the EU's Galileo positioning system, Russia's Global Navigation Satellite System and China's Beidou satellite navigation and positioning system. All these systems are similar o the GPS. The GPS contains three components:

- The space component: satellite system
- The ground control component: ground monitoring system
- The receive equipment component: signal receiver devices

The working principle of GPS is simple. The satellites of this system transmit ephemeris parameters and time information as a series of signals continuously. Users devices on land will receive this information and use the time gap of two times the signal has been sent to calculate receiver distance from the satellite to the receiver. The system needs the distance information of at least four satellites can be enough for navigation usage. The system uses these distances to calculate out a three-dimensional position of the receiver as the image from techwalla in Figure 1.2 shows[3]. This system can also calculate the speed of moving direction.

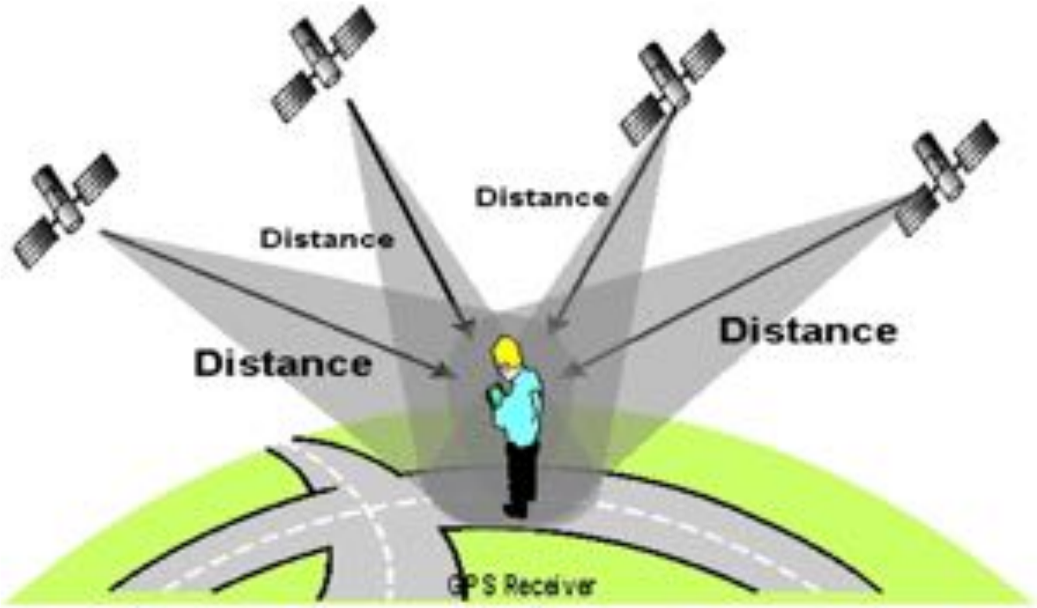

Figure 1.2: GPS working principle

The GPS is a perfect solution for outdoor navigation. However, it cannot be used for the indoor scenario because of these technology limitations:

- GPS signals are easily blocked or reflected by walls and other signal shields. If the wall is thick enough, the signal can be blocked or be attenuated. For example, GPS cannot work when the car passes through tunnels since the signal cannot go through a mountain. Moreover, sometimes, even the signals can go through walls and be received, the wall will also influence the speed of signals, and influences the navigation accuracy [4].

- GPS cannot provide altitude information correctly, and the error can be more than ten meters because of the earth reflection[5]. GPS can work well in the scenario when altitude information is not required[6].

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[3] https://www.elprocus.com/how-gps-system-works/

[4] https://www.techwalla.com/articles/advantages-and-disadvantages-of-gps-systems

[5] https://en.wikipedia.org/wiki/Geographic-coordinate-system

[6] https://support.google.com/maps

Moreover, the attitude information is essential for the indoor scenario because we need to take height information. For example, when a user in the mall wants to find a shop and the navigation system cannot provide which floor the shop is, it will also be difficult for the user to find this shop immediately.

- The accuracy of GPS cannot satisfy the need of Indoor environment. The error of the GPS is at most five meters, and the indoor context contains walls to attenuate the signal strength, increasing the error amount[14]. Even the latest Galileo system can make bias of navigation less than one meter for military usage[7], the accuracy is still not enough for indoor navigation.

1.1.3 Requirements for Indoor Navigation

The GPS navigation cannot be used for indoor scenarios. The next step, we need to analysis the main difference between indoor context and outdoor context to find out the requirements of indoor navigation.

The significant gap between indoor navigation and outdoor navigation is the requirement of accuracy. Indoor context is narrower than outside, and the navigation system needs to be more accurate to make sure the system can get the position of user correctly. Moreover, another difference between indoor and outdoor navigation is that outdoor navigation can usually give users pathways along streets, making route display these routes on smartphones[3]. The users only need to check out the route guide on a corner or crossroad to decide walking down which street. However, the indoor environment is more complicated. The system needs to find the walkable areas for users because some indoor areas are blocked by doors and cannot pass through. Moreover, walls also need to be taken into consideration by the system to generate a path to avoid going through these walls[8].

What appeals to indoor navigation is indoor navigation system needs find all the markers locations and user locations in the space with three-dimensional values in a real-time. Another essential requirement of the indoor navigation system is to get the map which can stand the structure of the building to be navigated. The visibility of indoor environments is always limited for users, and the system needs to get the full context to provide users with a series of pathways to the target location. To prevent the pathway

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[7] https://ec.europa.eu/jrc/en/publication/statistical-characterization-galileo-gps-inter-system-bias

[8] https://www.roseindia.net/services/tracking system/advantaesanddisadvantage-sofgps.shtml

makes user directly go through walls, the system needs to get information about the indoor context or the locations of walls. When the system gets the whole indoor context, it will be easier to generate a series of pathways which can avoid the walls and lead the user to the target location.

1.2 Methodology

The purpose of the indoor navigation system is for provide office buildings with a solution for guiding visitors to exhibitions. According to the analysis of requirements, the navigation system needs to have answers to these questions:

- Where is the current location of user?
- Where is the location of the target which is desired by the user?
- How to get the whole context inside a building?
- How to generate a pathway to avoid walls and makes user walk as less as possible?

To solve these questions, the system needs to have the ability to get current location visitors. The current location should be a three-dimensional vector value and needs to be accurate enough to work in the narrow contexts. However the GPS cannot provide the users with the accuracy locate information, we need to find other hardware to detect the current location and user movement in real time.

The system also needs to have the ability to find the target location. The target location needs to be saved by the system, and it can also be shared with different users who access to the navigation system. To deploy markers in real world, the best approach is the building manager deploys different markers as an object in three-dimensional map.

To get the whole indoor context, there are two approaches we can use. The first approach is using environment detecting devices such as a depth camera to observer the whole environment such as walls and floors and save them as a three-dimensional map. The second approach is using a sketch software to draw the three-dimensional map of building inside the context. When the three-dimensional map has been generated, the system can use this map to generate pathways for indoor navigation.

An excellent approach to make indoor navigation easier is to separate the entire three-dimensional into different parts and each part stand for a room to avoid the influence of walls. When the system tries to generate a pathway, the walls always stands for blocks, and the need to make sure our navigator avoid walls. Moreover, the system can make the user can only move inside each part inside the room, and the system can not make users directly move across the edge between two parts as Figure1.3 shows[39]. The only way to go across two parts is passing through the door between them, that means the finding the door position can help the system to solve the problem of walls. We can use the nav-mesh[9] function of the Unity game platform to segment the map. When we add these doors in three-dimensional map, we can destroy some parts of the walls to stand for doors, and the system can make the doors connect these areas, but still cannot directly pass through the walls. Moreover, when the areas cannot be assessed, as shown in figure 3.3, the blue area stands for the areas cannot be assessed, we need to keep the doors to these areas keep closed.

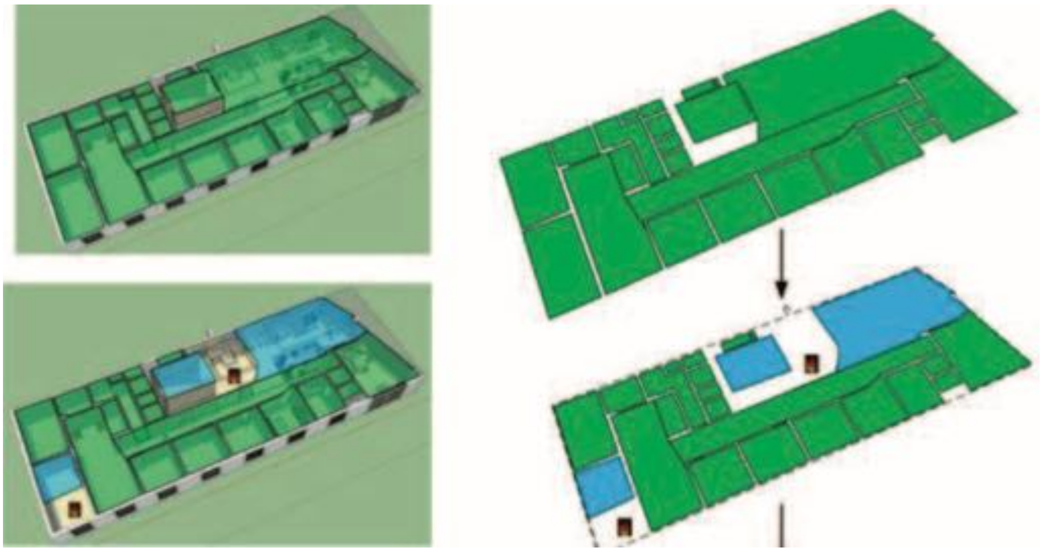

Figure 1.3: Room segment for indoor navigation

When the guide information has been generated, we need to solve some new problems below:

- How could the system combine the three-dimensional map with real world?
- How could the system the saved information be shared with different users?
- How could the system provide users instruction information?

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[9] https://docs.unity3d.com/Manual/nav-BuildingNavMesh.html

When the three-dimensional map has been generated, the most crucial step is to make connections between the map and the real world. We need to make sure that the map coordinate system directions are same as reality to make sure the system can detect movement direction correctly. The next step is to find a position in the real world which can also be found in the three-dimensional map. Moreover, we also need to make efforts sure the size value of the three-dimensional map is same as the real world. For example, if the distance between A and B is one meter in the real world, the distance of corresponding positions in the three-dimensional map should also be one meter. When these three requirements are satisfied, the map can correspond to the real world.

The navigation system also needs to have the ability to save and share the markers on the three-dimensional map with different users. A building can have many visitors at the same time, which means the three-dimensional map needs to be used by different users at the same time. A good solution is building a server and client framework to share information between three-dimensional map and user devices. The client-server approach also makes markers be deployed easier. The designer only needs to add objects on the server side, and all the clients will be updated. The designer only needs to add markers on the server side, and all the client can check this location on their device.

As we discussed, the indoor navigation system cannot provide visitors with a pathway along streets guide like outdoor navigation. The devices with screens for indoor navigation brings inconvenient to users because the indoor context is full of walls and other obstacles, visitors need to switch their horizon between real world and screen, that means the visitors cannot focus on the way. To solve this problem, navigate system needs to make sure the guide information can combine with real world. Based on this principle, we decided to AR technique to provide users with guide instructions. The best solution is using AR technology to generate a hologram, and the system needs to make the hologram move in the pathway which has been generated from the location the user is standing to the target position. With this solution, the guide information can lead the visitors clearly, what the visitor needs to do is following the hologram to target.

We decide to use a device which provides users with communication and AR function, and this device can also detect the movements of users correctly. We finally decided to use the Microsoft HoloLens for indoor navigation.

1.3 Contributions

Our contributions can be mainly separated into these parts:

- Developing a server to provide navigation instructions: We made a three-dimensional map on the server side to generate all the pathway information. And we send the navigation information to the HoloLens side to guide users to target positions.

- Bind relative position of three-dimensional map and reality: We made efforts on making our indoor navigation system find out the current location of users when HoloLens connect to the server. We use a software named Vuforia. This software is popularly used for AR projects on smartphones and other devices with cameras, and the Vuforia can bind a picture with an AR object, when the camera scanned the Vuforia picture, the Vuforia can generate an AR object. We can use this AR object as an anchor. That means the anchor will appear in the same place at both three-dimensional map and the real world. All the relevant position to this anchor will be the same of both three-dimensional map and the real world.

- Unify the size of reality and three-dimensional map: The three-dimensional model of a room can be complicated with reality. For example, if cartographer use Maya or 3DSmax as drawing software to build the three-dimensional map of a room, the size could be different from reality. There could be a difference between real world and map is the size difference, that means the three-map to be either amplified or shirked. To make the three-dimensional map has the same size with reality, we used Spatial Anchor the technology of HoloLens. Microsoft develops the spatial anchor for HoloLens and other mixed reality devices. This feature makes holograms fixed at a specific position. When the HoloLens visits this place next time, these holograms which attached with a spatial anchor can always appear at the same position. We attach four anchors at four corners of a room. In our experiment, we entirely attached twelve Spatial Anchors in reality. We also add these twelve anchors as game objects in three-dimensional map, which stands corners of three rooms. When the HoloLens connected to the server, the positions of these twelve anchors are sent to server.and the three-dimensional map is amplified or shrink until these anchors of reality correspond to anchors in three-dimensional map. We registered the amplifying rate for the next time usage. This method makes sure the size of three-dimensional map same as reality.

- New guide instruction method: We made a new user-friendly guide instruction system. Different from the current navigation be made on a smartphone, which provides a series of pathways to target, our navigate instruction uses an AR object in HoloLens to provide users guide service. When a user gives HoloLens a command to find a place, the HoloLens will generate a hologram in front of the user. We call this hologram navigator, and the navigator will be fixed in a pathway to avoid walls and lead the user to the target location. What makes navigator important for indoor navigation is navigator can make interaction with users. This hologram can detect movement and gaze angle of the user. When the user is too far from the navigator or the navigator is out of user horizon, the navigator will stop until the user gets closer or re-look navigator again.

1.4 Thesis Outline

This thesis separated into six chapters:

- Introduction: In this chapter, we describe the shortcoming of GPS and paper map for indoor navigation. We also list problems and requirements of indoor navigation. Then we provide our methodology with HoloLens and three-dimensional map to make indoor navigation. Then we talk our contributions of this indoor navigation approach.

- Related Works: In this chapter, we mainly focus on discovering the technologies for indoor navigation that have been used in recent years. After that, we talk about the advantages and disadvantages of these approaches. Moreover, we also study different approaches that could be useful for future work.

- Develop Requirements: In this chapter, we discuss the hardware and software will be used in this solution.

- Solution: In this chapter, we discuss the ideal solutions for our indoor navigation plan. Moreover, we also use the contents and approaches in related work to make a change of current solution if we find a better solution to other approaches.

- Implementation: In this chapter, we describe the approaches in details and what technologies we used. We introduce the approaches we used to make indoor navigation step by step.

- Evaluation: In this chapter, we design approaches to test the accuracy of our indoor navigation system. Moreover, use the data about accuracy to evaluate this navigation system to find out the benefits and shortcomings.

- Future work and conclusion : In this chapter, we first give the conclusion of all the work we made.After that, we describe what kind of application can be used on this system and what the make a preview of this system for museum indoor navigation.

2

Related Work

Navigation technology brings many benefits for the human life. With the widespread use of portable smart devices and communication technologies, navigation can be done on smartphones and smartwatches. Thanks to GPS technology, navigation has become an essential part of our life, and this technology makes our life convenient. However, as we mentioned before, GPS cannot work well for the indoor scenarios because of the limits of GPS technologies itself as mentioned by Nirjon et al. [27]. New technologies need to be used for indoor navigation.

In recent years, mobile devices with different sensors to detect movements and environment makes indoor navigation possible. The inertial measurement unit (IMU) can detect movements and origination. Moreover, some research uses devices to emit signals such as Wi-Fi and blue-tooth to detect the distance of the user from these devices (see Boogaard, Shi,Nirjon et al. [32, 31, 27]). These approaches provide navigation system data to calculate the real-time relative locations as mentioned by Li et al. [21]. Moreover, each new technologies have advantages for to be used, but they also have limits such as accuracy, reaction speed and cost as mentioned by Wijewardena et al. [34]. In this chapter, we introduce the different technologies that can be used for indoor navigation firstly. After that, we provide an overview of the works for indoor navigation techniques the researchers have done in recent years, and also analysis can these approaches work well to solve our problems.

2.1 Navigation Workflow

Before we analyse different approaches to navigation, we need to understand how a navigation system does work. We need to understand about what data does this system need and what data this system provides to users, and we also need to know how does system use these data to generate pathways.

Both indoor and outdoor navigation systems need to follow these basic principles to get information from the user. A navigation system needs to contain these features:

- Get current user position: This data value should contain longitude and latitude values or the vectors stands for position in a flat for the navigation system, the height value is also needed for indoor navigation;

- Get target information: Users who need to be guided should provide the information to describe the target, the information could be the name or other descriptive information to make the system find this target. Moreover, when the system finds this target name, it also can get the target position;

- Generate pathways: When the target has been found, the system needs to generate a pathway and send this information to the user;

- Navigate in Real-time: The system also can detect user position in real-time to decide the user is in the right pathway, and when the user has arrived to target position, the system also needs to detect it and stop navigation procedure [1].

Indoor navigation procedures are in generally the same as the outdoor scenario, which consists of indoor localisation, routine plan and monitoring users current location to judge is the user in routine or not as mentioned by Liu et al. [22]. However, as we discussed before, indoor navigation also requires more information to make it work well in the indoor scenarios. A report on the Worcester Warehouse fire accident indicates the importance of context awareness for indoor navigation as mentioned by Fischer et al. [10]. The system needs to detect the context of indoor environment to avoid navigation system lead users to go through walls and dead ends. Another report is about navigating visitors cannot use outdoor navigate approaches such as GPS technology because accuracy is not enough as mentioned by Jain et al. [17].

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[1] https://www.loc.gov/rr/scitech/mysteries/global.html

2.2 Indoor Navigate Technologies

In some malls, the shop owners try to attract visitors by using posting advertisements on the information walls with their address or paste arrows on the ground with their shop names to lead users to these shops. This idea is a kind of landmark approach as mentioned by Zheng et al. [38]. The landmark can help users to find a place they want to visit. The navigation system also uses this principle to save different target places as landmarks, when the user gives a navigation request, these landmarks will be found by the system. The important approach for the indoor navigation system is to get the location of the user. The system needs to use *Simultaneous Localization and Mapping* (SLAM) approach[2] to get the current visitor position. Recently researchers make efforts to use different technologies for indoor location detection. These approaches mainly are implied in four different ways:

- The Receiving Signal Strength Indicator technology: this technique uses radio signals emitted by different devices to calculate the locations of users. These markers, such as Wi-Fi signals and Blue tooth signals, can be received by devices carried by users and calculate out the current location and find target locationas mentioned by Ivanov, Corna and Bell et al. [16, 6, 3];
- The Markers Recognize technology: The second approach uses the imagine markers in the museum, which could be paintings, QR codes and even exit signs combine with other view scenes in rooms to find scenes which can be recognised. These markers can be detected by the camera of navigation devices that provided by the museum when the camera detected a specific marker to get the current location of the user as mentioned by Gimeno et al. [12];
- The Context-Aware Navigation technology: The fourth type is to use three-dimensional scan devices, such as an inferred light device or three-dimension camera to detect the context. These devices can then calculate out current position relevant to the room environment, and this technology can also be used to find out obstacles like the walls and other objects to generate a room 3D object with same as of reality to make users avoid collides as mentioned by Chen and Mulloni et al. [5, 25].
- The IMU Sensors Navigation technology: The third type is used *inertial measurement unit* sensors to get the relative movement of the user.

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[2] https://pdfs.semanticscholar.org/d495/66b006f9ec3e696dfd5357c556479ae01a2c.pdf

> The users can carry the devices such as smartphones, which contain sensors to detect the movement distance, height and rotation of users to calculate the movement distance. The system only needs to know the initial position of the user and can calculate out the current location via the data registered by sensors as mentioned by Gerstweileẽt al. [11].

2.2.1 Receiving Signal Strength Indicator

Wireless signals can be used for indoor navigation. This system is named Indoor Positioning System (IPS), this system uses lights, radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices[3]. The users keep mobile devices with them to receive signals from different sensors, and the device can calculate out the current position by using these signals received by these sensors in real-time [4]. We call this technology Receiving Signal Strength Indicator.

Gradient Wi-Fi Spotting

Gradient Wi-Fi spotting technology is popularly used recently, as we know, our smart can detect the strength of Wi-Fi signals when we use Wi-Fi signals for internet connection. Signal strength can reflect the distance between the Wi-Fi router and the mobile devices as mentioned by Ivanov, Corna and Bell et al. [3]. That makes Wi-Fi technology be used for indoor navigation these years. Each Wi-Fi router has a unique name, mobile devices which carried by users can detect these routers, and can also sense signal strength of them to calculate current user position. This approach has been used in some places as mentioned by Shi et al. [31]. Currently, a group uses smartphones to detect different Wi-Fi signals strength to Receiving Signal Strength Indicator(RSSI) values. These values can stand for the distance of users to routers. So when the router positions are known, as the Figure2.1 shows, Wi-Fi detection can use at least four routers to calculate out current position of user as mentioned by Carrera and VandenBoogaard et al. [4, 32]. Each device has a unique MAC address[4], which means the mobile devices will not be influenced by each other [3].

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[3] https://en.wikipedia.org/wiki/Indoor-positioning-system

[4] https://en.wikipedia.org/wiki/MAC-address

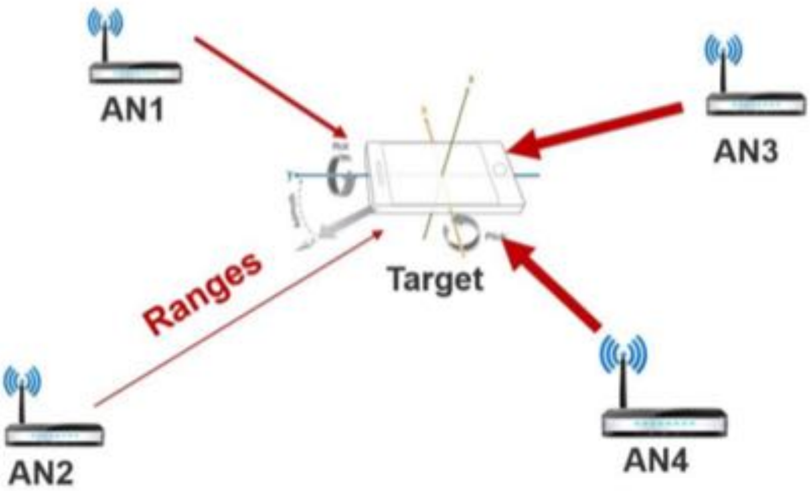

Figure 2.1: Wi-Fi technology for indoor navigation [4]

The advantage of the Wi-Fi signal is the signal emit devices can be easily deployed [31]. The Wi-Fi navigation can also save energy of smart devices as mentioned by Neishaboori et al. [26] because Wi-Fi communication devices do not consume too much energy, and makes navigation devices work longer. Each device contains a unique MAC address makes each user can get their service. The reliable can be guaranteed because when a Wi-Fi router is down, and the other routers can still detect current user location [3].Moreover, Wi-Fi indoor navigation suitable for museum navigate scenario because of the high accuracy. According to the test results of Zhejiang University, the error of Wi-Fi navigation could be 0.4 to 2 meters [31].

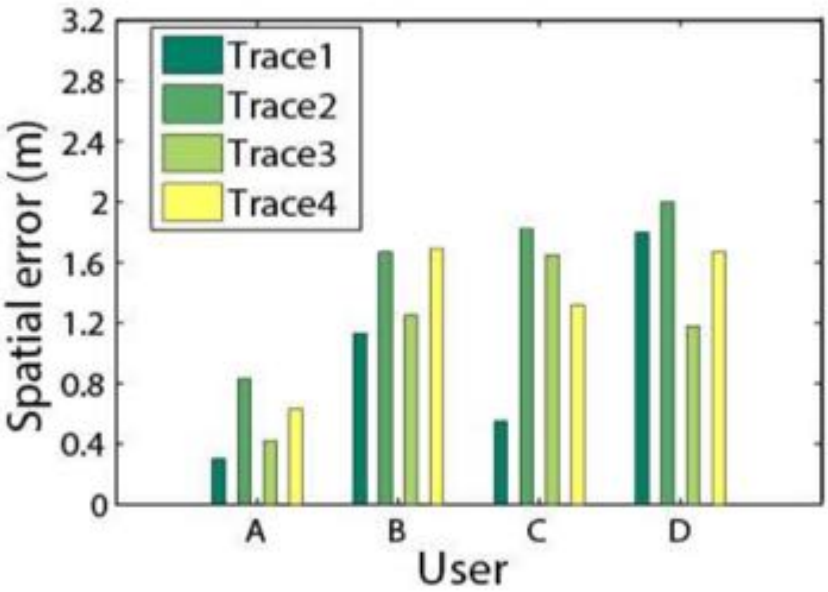

Figure 2.2: Wi-Fi spatial error of different users [31]

However, this technology is not perfect for the indoor navigation. At first, the Wi-Fi signals cannot be used to detect user rotation [3], and this shortcoming makes trouble when the pathways are behind the user, which makes trouble for users to find the navigator.

Bluetooth

Bluetooth is a technology be used for small volume data transformation. Same as Wi-Fi signals, each Bluetooth signal emitting device has a unique number to be identified. Bluetooth can also be used for indoor navigation. Recently, some teams use Beacon devices and smartphone for indoor navigation. These Beacon devices can emit wireless signals in a limited range if the smartphones in this range and they can receive this signal. The navigation system can use a significant number of Beacon devices to cover the full environment [6]. Same as the algorithm of Wi-Fi navigation, each beacon has one unique Beacon ID, the system needs to detect the distances between the user and at least four beacon devices to get the current position of a user [6]. A Japanese group did a project named StaNavias mentioned by Kim et al. [18] which uses this technology to help blind people in train stations finding locations like shops and rest rooms of airports. As Figure2.3

shows, this system can use Beacon to get the current location of user, when the system find the target which is desired by user, it will generate a series nodes as checkpoints of a pathway, and the system will give user voice guild, when the user arrived to the range of the next Beacon group, it will provide user the next pathway instruction.

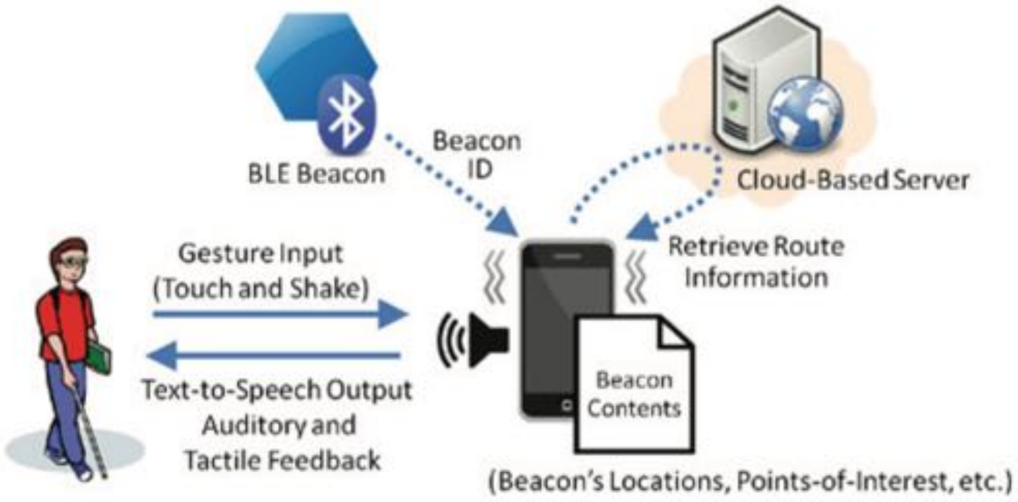

Figure 2.3: Structure of StaNavi [18]

Indoor navigation with Bluetooth signal consumes less power than the Wi-Fi devices, a Beacon device can last few years without charging makes these emit devices easier to be maintained [5]. The accuracy of beacon devices is also good, the error at most two meters [6] makes indoor navigation is possible.

However, Beacon devices have some shortcomings. The beacon devices are energy saving devices, that means the signals can be influenced by other signal noises[7]. Another shortcoming of the Bluetooth signal is delay issue, and the delay could be more than 25 milliseconds with large data transformas mentioned by Moron et al.[24]. The delay can be accumulated and makes the system cannot get the latest location of users. Moreover, the Beacon system needs to cover areas inside a building, and each Beacon cover range is only seven meters [6], that means the system needs more beacon to emit devices

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[5] https://community.estimote.com/hc/en-us/articles/202552866-What-s-the-battery-life-of-Estimote-Beacons-Can-I-optimize-it-

[6] https://reprage.com/post/How-accurate-are-estimote-ibeacons

[7] https://www.goldtouch.com/stop-bluetooth-interference-messing-devices/

to make up short distance transform issue, and if one Beacon cannot work, it can make user in this area cannot be detected.

2.2.2 Markers For Indoor Navigation

Another type of approaches to help system finding out current user location are by using markers in the real world, and the systems also need to have the ability to recognize these markers to find out the current location of users. This approach can be made by use imagine recognize [19] or Radio-frequency identification (RFID) [16] technologies.

Natural Markers

This approach was used in Casa Batllo museum, and the original purpose is to combine exhibitions with AR technology to provide users with new experience [12]. The potential natural markers are, for example, fire extinguisher markers, signs with textual information hints or posters with special graphics shapes [23]. When the natural marks are found and recognised, the current location can be decided, and the system can combine this technology to detect the relative movement to this marker and calculate user movement in real-time [38]. This approach can also be used for AR technology as mentioned by Koch et al. [19]. AR objects with markers are more stable and stay at a place precisely than objects without markers, and this technology can avoid noise like the light direction as mentioned by Viyanon et al. [33]. As the Figure2.4 shows, the system can detect the current location by using the exit icon in a room, and the system can generate an AR arrow to lead visitor to target [19]. Currently, the Vuforia uses this technology to generate AR objects with markers in a fixed location[8].

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[8] https://www.vuforia.com

Figure 2.4: Exit icon as AR natural marker for indoor navigation [19]

The advantage of picture markers is system does not need to deploy extra devices in museums, and it can use posters and exit icons on walls as markers. This technology can make the system get user rotation, makes guild instruction more accessible, when the user needs to turn left or right [19].

However, this technology has some problems makes position identification difficult. The imagine recognise depends on the quality of the camera, and light near markers. Moreover, when the distance between the image and the camera is too far, the system will also have trouble to recognise this marker [19].

QR Code Marker

Quick Response (QR) code is similar to Natural Markers, they both depend on using imagines to find location. The difference of QR code marker is this technology uses a series matrix barcodes to represent a unique identity[9]. Based on this feature, the navigation system can figure out current location by using smartphone to scan the near by QR codes and the system can find the current locatoin based on the QR code [19]. As Figure2.5 shows when users scanned QR code with their smartphone, this code can take their smartphones to a web page and make user select desired place and provide user instruction to this position[10].

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[9] https://en.wikipedia.org/wiki/QR-code

[10] http://www.myvflow.com/Tools/Navigation

Figure 2.5: QR marker be used for indoor navigation

QR code technology can be used to find location and rotation of user with great accuracy as mentioned by Angeles et al. [2]. Moreover, compared to the genetic markers, each QR code are unique, that means when the camera has detected this marker, the position can be sure by navigation system [19].

However, the QR code approach has a problem since these codes cannot work well in a dark environment. Usually, the QR codes cannot work well at the far distance from cameras. Moreover, the second problem is the indoor environment can be crowded witch makes other visitors hiding these markers as Figure2.6 shows [10].

Figure 2.6: QR be hidden by other visitors
[12]

RSNAVI

RSNAVI is an RFID-based context-aware indoor navigation system, the purpose of this system is helping blind people moving in an unfamiliar environment. This approach contains RFID passive tags to help user tracking object localisations. The system uses four-dimension modelling(three-dimensional building with geometry information) [15] to represent user location and rotation. The sensors are electronic accelerometer and magnetometer (compass) to detect movements of user as mentioned by Fallah and Serra et al. [8, 30]. The system uses Mobile phones or other devices with integrated Near Field Communication (NFC) interface, making RFID markers be detected if the user arrived at a known position. Users can receive this information via the NFC interface of smartphones. When the user has a target, the system will find RFID tags near the user and generate a path to go through a series of RFID tags as path nodes. When user arrived a node, it will give the user instruction to arrive another node until the user finds target as mentioned by Jain et al. [17]. So when the user is close to a marker, the smartphone will give them voice feedback to guild user to the next marker [15].

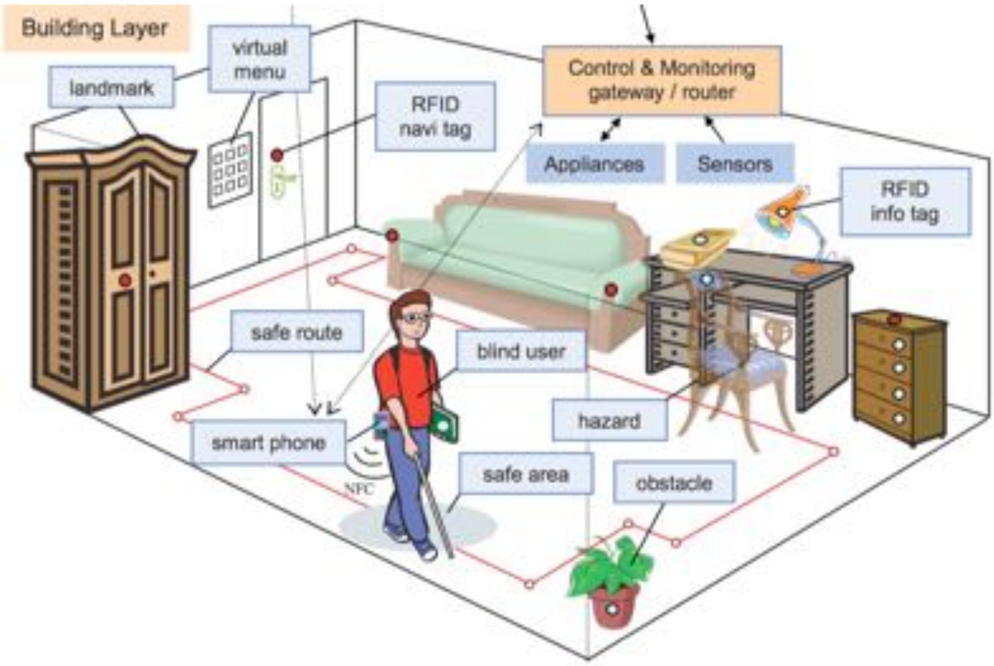

Figure 2.7: RFID technology for indoor navigation

The advantage of this approach is the system contains different sensors to combine with RFID tags and detects both position and location of users. RFID tags near obstacles will give user voice feedback when the user arrives at these places [15]. This approach makes sure the accuracy and safety of blind people.

However, the shortcoming of this approach is this system is too complicated because it needs to deploy a lot of tags in rooms. The smartphones cannot always detect RFID signals if the distance is too far from tags [19]. Moreover, the biggest issue of this system is the user group, and ordinary people would notice obstacles in rooms, it is not necessary to use RFID markers to tag them.

2.2.3 Context-Aware Technologies

The context-aware technique is a technology to detect the environment near users to find out user current location. There are two approaches are used for environment detection. The first approach is using imagine processing to detect the environment. This approach needs to use the camera of smartphone and register video of the environment and seprate this video as a series of imagines with user movement information to calculate out a map as mentioned by Gleason and Dong et al. [13, 7]. Another approach is using depth scan technology to capture the environment and generate a three-dimensional model of a room. When the spatial mapping is captured, it can be used to clarify the navigation spaces and calculate paths [9].

Image Processing Detection

This technology uses the smartphone camera to record videos, and the video can be separated into a series of pictures, the system can add dots on these distributed pictures, the system needs to deploy more dot if this place contains objects like walls, and will also deploy fewer dots in empty places. Moreover, the system also uses IMU sensor to detect user movements in a room, the system separates the picture every second, and system also register the movement vector of this value combines with each doted picture [13], and these dots can be converted into a three-dimensional dots cloud. With the overlap of these dots as figure2.8, the system can generate a three-dimensional model to stand the indoor context [35]. To solve this problem a research group at Aalto University, Finland published an approach named iMoon to solve the problem of image-based detection with IMU sensors and Wi-Fi fingerprinter. The iMoon project uses 3D points clouds in every imagines and make these points with density on imagines [7].

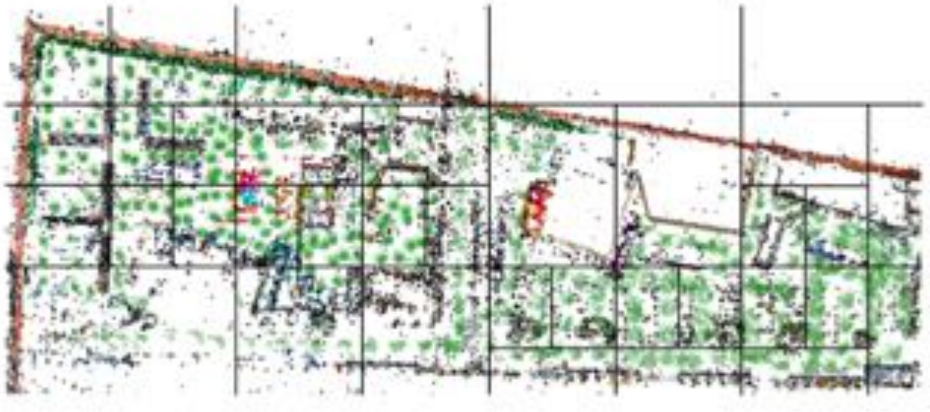

Figure 2.8: Example of dots cloud in three-dimensional [7]

To reduce response delay to improve the accuracy of localisation, iMoon partitions three-dimensional models based on the density of three-dimensional points cloud, and selects partitions for image-based localisation using Wi-Fi fingerprints to locate the user and also use internal sensors to find out movements [7]. The iMoon server at first get camera position of each photo and generate camera points. Moreover, between successive calibration points, the iMoon server computes movement between these two points based IMU sensor. So these movements data can be used to combine with three-dimensional map to generate a navigation mesh upon the three-dimensional points clouds [7].

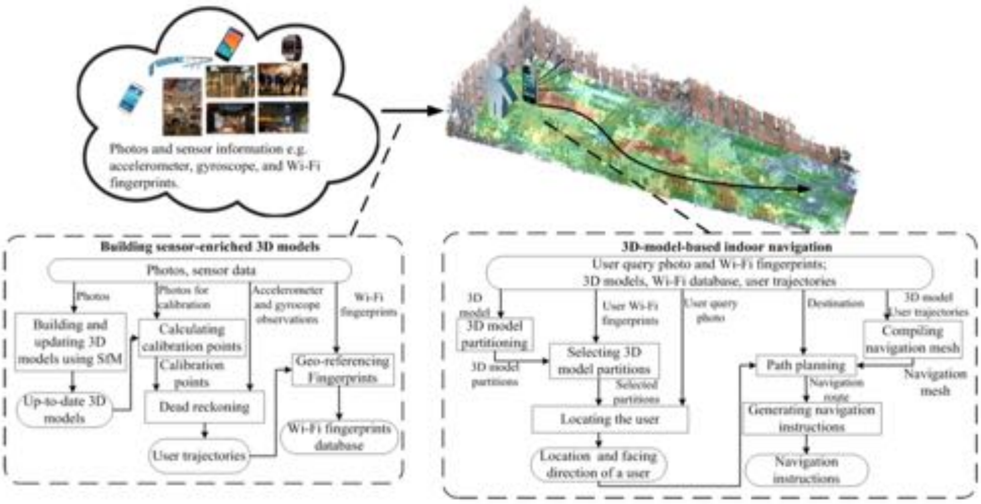

Figure 2.9: iMoon work flow [7]

Based the data detected by cameras, the system can figure out indoor structures to sense the environment, and also use IMU sensor to get rough movement information to avoid the camera detect similar locations as mentioned by Huang et al. [14], the data from cameras can combine with position information detected by IMU to represent the indoor environment. These approaches can discover the indoor environment and register these data to generate a map, and use the movement data to calculate a navigation mesh to avoid collides [7]. This approach is excellent because it solves the shortcoming of other technologies that cannot detect the environment. The context can be saved as a map of the building, and this map can be used for path generation. However, this technology cannot detect environment well in wake light scenario, makes finding the points for three-dimensional cloud difficult [38].

Depth Camera Based Detection

Recently, a solution for fire-fighter navigation has developed. This solution focuses on buildings contain heavy smokes during the fire accident and cannot be visually detected by human eyes or cameras. This solution combines both thermal camera and depth camera techniques to scan the depth on walls of environment objects and to generate a 3D model which stands for room surfaces [29]. This approach uses a head-mounted display (HMD device) and AR technology to provide firefighters with landmarks and share with others as figure2.11 shows [1].

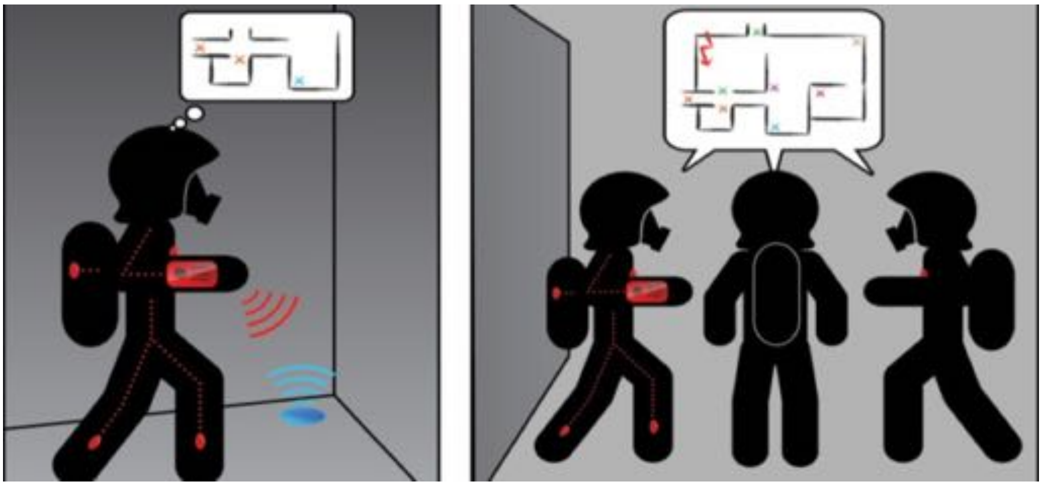

Figure 2.10: Augmented landmarks sharing [29]

The depth cameras can provide the navigation system with at least two cameras to generate a three-dimensional model of the environment. The most outstanding depth camera is Microsoft Kinect. The Kinect can directly sense the environment into the third dimension and also detect movement of user [37]. The depth camera technology is used for robot navigation by a group in Korea. This approach uses a depth camera and IMU to find out robot position in real time and also register room in three-dimensional map to show the relevant position of a robot in this three-dimensional map [35].

The depth camera is also a good solution for indoor navigation because it can use the shared points to provide other users with guidance, this mythology can be used for the indoor navigation system to find the target place. This approach can also detect the user position in real time and share with other users. Moreover, this technology can also be used for scan-out the environment.

However, this technology cannot scan out the environment very fast, and even the depth camera can scan out some of the indoor contexts, it cannot thoroughly scan all the indoor context. Moreover, if there is a glass wall in the room, the depth camera cannot scan out this wall. If the indoor walls are not thoroughly scanned, the path generates function cannot be correct all the time and leading the users to the dead end.

2.2.4 Internal Measurement Unit Technology

Inertial Measurement Unit (IMU) sensors can also be used for indoor navigation. In some studies, IMU is used to combine with other technologies to help camera and radio signal sensors detect relevant movement [34]. Currently, most existing indoor navigation solutions integrate a compass to sense the magnetic field and also use gyroscopes[11] to detect user movements as mentioned by Carrera et al. [4]. This technology can only detect relative movement of users and needs to combine with other indoor navigation technologies to improve navigation system accuracy as mentioned by Noreikis, Zheng, Carrera and VandenBoogaard et al. [28, 38, 4, 32]. Currently, a technique named Sensor Fusion for Robust Tracking is used for indoor navigation as mentioned by Kundu et al. [20]. This technique has a series of workflow to use the camera and IMU sensors, and the system gets both visual and internal sensor data to calculate out current user location. This system needs to obtain an initial position and orientation at first from the image based localisation.The camera can capture the current location's image, this imagines can be calculated into a six DOF camera pose. Once the response arrives, the mobile client calculates the rotation angle between projections of an inertial sensor based and an image based direction vectors. After that, the mobile client estimates the floor level based on relative device orientation. Mobile devices finally calculate out the position of the user based on the first location [28].

The purpose of using IMU sensors it to combine other technologies we mentioned to improve navigation accuracy. This technology is popularly used on robot movement tracking [20] and AR on smart phones as mentioned by Flores et al. [36].

2.3 Analysis of Approaches

The RSSI approaches can be used for monitoring user current location in real time. However, all these approaches cannot provide the information about context in this building, that means the system cannot generate a pathway to help users avoid walls. Moreover, the RSSI approach cannot be used to detect the forward location of users, making indoor navigation difficult. To solve the issue of context recognize, using depth cameras to detect the indoor context and save these context data for pathway generation. The IMU sensors can be used to detect the movements of users. Moreover, if the system knows the initial location,the system can use the initial position

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[11] https://en.wikipedia.org/wiki/Inertial-measurement-unit

and movement information to calculate the position of users in the building. These markers are used to help system find the initial location, we assume the Vuforia can be a good solution to help the system get initial location. According to all the requires of this navigation system, we need a device which contains a depth camera, IMU sensors and a good camera with it. The Microsoft HoloLens is a good solution to satisfy all the requirements, and we decide to use the HoloLens for indoor navigation.

3

Develop Requirements

The HoloLens is an untethered, independent computer with a Window 10 system. Users can wear the HoloLens comfortably on their head. Hololens is known as a mixed reality device, which can blend the real and digital worlds [1]. HoloLens can generate AR objects and place them in the real world, and this object can be fixed in the position like they are real-world objects. Different from VR technology, which immerses users in an environment and they typically do not see anything in the real world around. Moreover, AR tries to enhance the world around users with extra data, such as markers, or heads-up information that may pertain to their location. The HoloLens can let developers design applications to understand the indoor room and have interaction with the real world. For example, the HoloLens can understand walls and post windows of apps on the wall, and when the user comes back again, this windows can still stay there. So the user can also ask HoloLens to generate AR objects can drop them on tables.

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[1] https://msdn.microsoft.com/en-us/magazine/mt788624.aspx

3.1 Hardware

3.1.1 Display

The HoloLens uses optics to display. These optics are lenses that make a light project on it and makes users see through it. They can provide 2 16:9 light projectors to make sure the user can see holograms in both eyes. The optics can automatically adjust the papillary distance to make sure all the view is always clear. The resolution is 2.3M light points[2], comparing to other VR devices at the same time, the HoloLens can provide better quality objects.

Figure 3.1: HoloLens optics

3.1.2 Sensors

The HoloLens contains a series of sensor to make this device understand the environment, gestures, voice commands and user movements.

- Environment understanding cameras: HoloLens contains four environment cameras. These cameras provide the user with a fixed location in space and pose. The environment cameras combine with IMU to make position detection faster.[3]

- Depth camera: a depth camera uses the same technology as the Microsoft Kinect to measure the depth of the context surface. This camera

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[2] https://www.slideshare.net/MatteoValoriani/mixed-reality-from-demo-to-product

[3] https://www.tomshardware.com/news/microsoft-hololens-components-hpu-28nm,32546.html

can measure a distance from the camera to objects in the room when the depth data has been measured, HoloLens can generate a 3D object that stands for the surface of the object has been measured. This sensor is important because it can be used for spatial mapping to the aware environment.

- 12MP camera: this camera can be used for recording and taking pictures, and currently it can also combine with Vuforia technology to connect 2D picture mark recognise to help the Hololens find the current location.

- Ambient light sensor: this sensor can detect light of environment to adjust optics light to make sure holograms can always be viewed clearly by users.

- Microphones: makes positive interaction, the HoloLens also contains microphones to receive voice commands of the user. When the user speaks a command that been detected by HoloLens, it will execute to this command if this command has been registered.

- IMU: the IMU sensor is used for detect movement and rotations of the user. The indoor navigate system needs to know the current location of users in real time, and with IMU can help system to get relative movement of the user from the original location[4].

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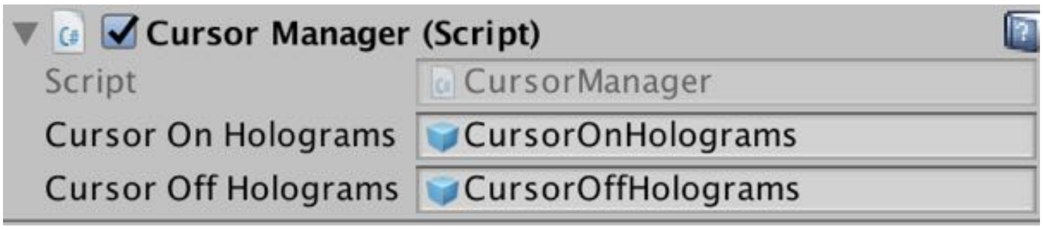
[4] https://www.slideshare.net/Codemotion/hololens-primo-contatto-marco-dal-pino-codemotion-milan-2016

Figure 3.2: HoloLens sensor bar

3.2 Unity Game Platform

The Unity game platform is widely used for game developing. This game platform is robust and can fit into different operating systems. Unity is different from other game engines developing for the powerful gaming computer or game consoles, which require high energy on GPU and CPU, Unity can be used to develop games for mobile devices such as smartphone and tabs which do not requires too much power. Unity can provide each game object in a scene with physical values to simulate the real world. Moreover, it contains thousands of packages to simulate reality with different physical values and fancy effects.

Developing on Unity is not difficult for developers. This game platform can use either JavaScript or C# as programming languages. In Unity scenes, the basic units are game objects, and these game objects can contain real shape or only as a folder to combine other game objects to become a group. We can also attach control scripts, and different mesh renders scripts on these objects to control these objects. Moreover, Unity can also attach scripts on a game object and make this game object be saved as a prefab. These prefabs can be used in different game scenes. With this feature, developing with Unity can be easier because the developers only need to add prefabs in other scenes for re-utilisation. The APIs of Unity makes describing the relationships of different game objects easily to be described, developers can add a public game object as a feature in a script, as Figure3.3 shows, there will be a window among this script, this window is a public game object. Developers can drag and drop a game object in this window directly to make operation and communicate with this game object in this script. Unity can also be used for cross platforms developing. The developer can choose the build platforms to run on different platforms. This feature can make software transplant easier to be applied.



Cursor Manager (Script)

Script	CursorManager
Cursor On Holograms	CursorOnHolograms
Cursor Off Holograms	CursorOffHolograms

Figure 3.3: Game Object be added in scripts

Unity also provides VR and AR developers useful APIs and packages to make the development for AR and VR easier. A ToolKit be used for Microsoft HoloLens and Windows Mixed Reality Headset named Mixed Reality Toolkit is published by Microsoft in February 2017[5]. This toolkit is a series of scripts and prefabs that makes developing on HoloLens easy. The developers can drag and drop some prefabs in a scene directly to make primary functions such as spatial mapping and voice commands work. Developers can make develop base on these essential functions by adding extra scripts and add these Mixed Reality Toolkit prefabs in these scripts.

Microsoft Hololens developing relies on Unity. For the AR environment developing, developers can directly drag game objects in the game scene as AR objects in the real world, and these AR objects will be fixed in a position even user wearing HoloLens moves. If these objects contain physical features, this AR objects will behave like real objects. For example, when we give gravity to a ball, we can drop this ball on the ground, and this ball will also roll with the view of HoloLens.

3.3 Vuforia

Vuforia is an augmented reality software development kit (SDK) for mobile devices that enables the creation of augmented reality applications[6]. Vufo-

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[5] https://hololens.reality.news/news/why-is-most-hololens-development-happening-unity-0173966/

[6] https://en.wikipedia.org/wiki/Vuforia-Augmented-Reality-SDK

ria uses computer vision technology to find and track imagines and three-dimension objects, such as boxes, in real time. These images and three-dimension objects are called Vuforia targets. When these tags are saved in Vuforia database, and each Vuforia target will correspond to an AR object in the real world with a fixed size and relative position to the Vuforia target, concerning real-world targets when the camera of mobile devices detects them.

Vuforia can work well with the Unity game platform. Developers can directly import a Vuforia package to the Unity game engine, and all the development kits can be used. The Vuforia can work well with Mixed Reality Toolkit, that means the developer can use the camera of HoloLens to detect Vuforia targets in the real world. This technology requires developers to make a Vuforia target which binds with a picture, to make the distance and size of AR object same as the size and distance from Vuforia images in Unity.

3.4 Mixed Reality Toolkit

The Mixed Reality Toolkit is an open source project to share foundational components, building blocks for interactions in Unity[7]. This toolkit contains all the essential features for HoloLens application development.

3.4.1 Interact Functions

Currently, the mixed reality has these interaction features below:

- Input: users can use the input module, camera, cursor or motion controllers to interact with AR contents. The most widely used functions are cursor and gesture. They are basic features for HoloLens interaction. The cursor is an indicator of the user current gaze vector, provides continuous feedback for the user to understand what HoloLens understands about their intentions. Also, gesture function can detect hands and finger movements to recognise them as drag and tap, and these gestures can be used for user interaction with HoloLens.

- Intractable Object: Intractable Object makes hologram objects respond to standard input states such as focused and pressed. In mixed reality scenes, a button could be any AR object which exists in the environment, and they do not have to be a flat button that we are using on

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[7] https://medium.com/@dongyoonpark/open-source-building-blocks-for-windows-mixed-reality-experiences-hololens-mixedrealitytoolkit-28a0a16ebb61

smartphone screens. It is essential to provide clear visual feedback on these intractable AR objects to make users understand the object can be operated or not.

- Voice Command: Voice input is a natural way to interact with an object in mixed reality. It can help users to reduce the time and minimise effort. Windows Mixed Reality shell provides system level commands such as Select, Close, Move This and Face Me to interact with windows.

3.4.2 Spatial Anchor

A spatial anchor represents a point which can be recognised by the HoloLens in the real world. The system will keep tracking this anchor location overtime and AR objects bond with anchor will. Each anchor has a coordinate system that adjusts as needed, relative to other anchors or frames of reference, in order to ensure that anchored holograms stay precisely in place. By saving spatial anchors to disk and loading them back later, the AR hologram can remain at the same place in the real world all the time.

For example, rendering a hologram in an anchor coordinate system gives users the most accurate positioning for that hologram at any given time. This comes at the cost of small adjustments over time to the hologram position, as the system continually moves it back into place relative to the real world.

While spatial anchors are great for holograms that should remain fixed in the world, once an anchor is placed, this location will be registered in HoloLens unless this AR object is moved again. In our solution, when a spatial anchor has been placed, the HoloLens will send the current location to the server side, and the server will save these position that has been deployed and share these anchors to other users.

3.4.3 Spatial Detection

This function uses spatial detection sensors to observe the environment in front of the user when room inside surface is scanned, and the HoloLens will generate one or more bonding spaces with a set of spatial surfaces[8]. The purposes of spatial detect are to ensure holograms can interact with the environment and improve movement detect accuracy. The IMU sensor can detect device movements, but it cannot always give the system a correct result when the users stop walking, the IMU sensors have memory effect, when the HoloLens stops moving, there will be an error in the zero value that messes up inertial navigation over a longer time. With spatial mapping

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[8] https://docs.microsoft.com/en-us/windows/mixed-reality/spatial-mapping

function, the HoloLens can also use depth camera to calculate the distance from user current position to a wall to improve navigation accuracy.

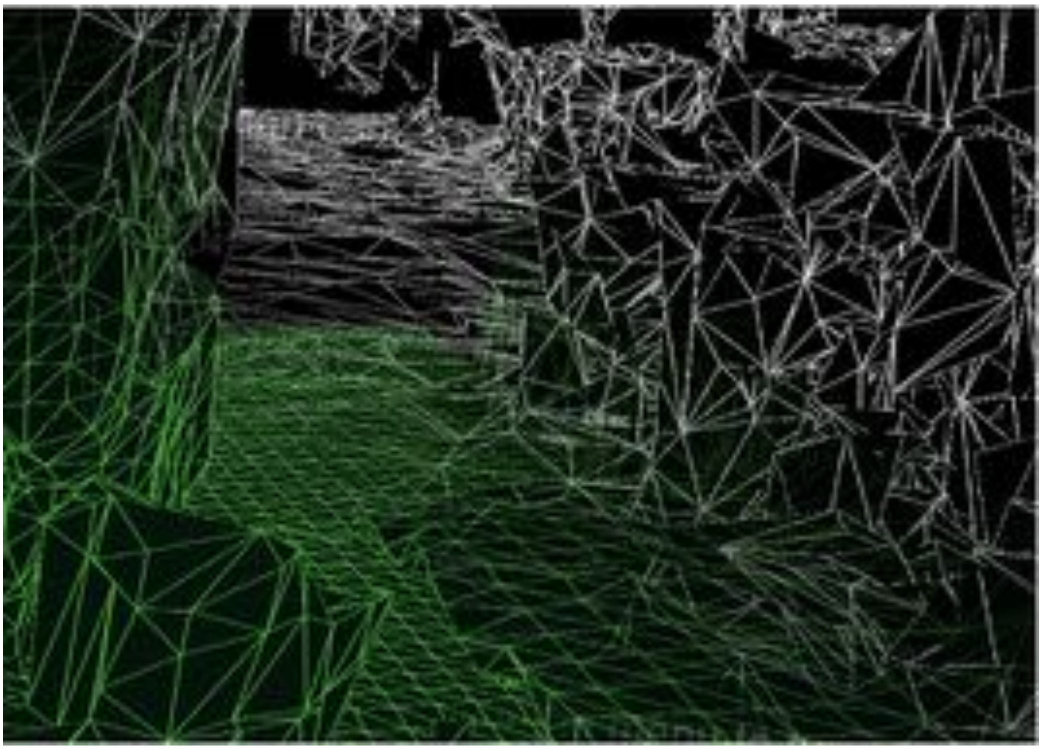

Figure 3.4: HoloLens Spatial Detection the real world

4

Theoretical Solution

4.1 Indoor Navigation Workflow

We described the approaches made by other research groups in the related work. All these navigation approaches need to follow the basic principles for indoor navigation. At first, the system needs to search the target which desired by the user. When this object has been found, the system needs to get the position of the target. When the user gives a search command, the system needs to get the current user position for pathway generation. The system needs to consider the indoor context when generating pathways because it will make the indoor navigation system useless if users are led to go through a wall, which means the navigation system is not useful. Some buildings contain many rooms, that means navigation system cannot ignore the influences of generating a pathway. Finally, this navigation system also needs to have the ability to judge if the user arrived target location or not.

Following these requirements for indoor navigation, the indoor navigation system needs to contain at least four features: At first, the system needs to save information about indoor exhibits, and the information needs to be a name and location. Second, the system needs to have the ability to find these locations that be saved when the user gives a search request. After system found target location, a pathway needs to be generated. The initial point of this path is current user location, and the endpoint is the target position.

This pathway also needs to consider obstacles like walls to avoid leading the user a pathway to go through a wall. When the pathway has been calculated, the system needs to provide users with a guidance information to the target position location.

4.2 Basic Functions

According to the requirements of indoor navigation, we can separate the users into building managers and visitors. Building managers need to deposit markers for exhibitions and also add extra information about exhibitions. Visitors need guidance information which is provided by building managers.

For the managers, an indoor navigation system needs to provide a service for adding information about exhibitions. There are two approaches to save targets. The first approach is directly adding information in the three-dimensional map in the server side. Another approach is depositing AR markers directly on HoloLens side. When a marker has been deployed, the name and position will be sent to server side and be saved. The purpose of this approach is to make sure all the information can be shared with other users for the further use.

For the visitors, an indoor navigation system needs to have the ability to recognise the current location. That means the three-dimensional location value on the client needs to be same as the value on three-dimensional map on the server side. This system also needs to make sure these locations be updated to make sure users can get access to the latest data. When the user gives the system a command to find a place, the system will find all the names of markers on the server. When the command has been found, the system will generate a pathway from the current user location to the target location and avoid obstacles. When the path has been generated, an AR hologram will appear in front of the user. We call this object navigator. The navigator can follow the pathway that is generated by the server and leads the user to the target location.

4.3 Working Procedure

4.3.1 Get Spatial Map

As we discussed in the related work, the indoor navigation needs to detect the indoor context for pathway generation. The depth cameras could be used for movement detecting[1]. We also tried to save the whole indoor environment with the spatial mapping function. However, this function cannot work well according. We noticed HoloLens could detect the surfaces of inside the room with the spatial mapping function, but it makes errors during saving, the HoloLens spatial mapping can detect surfaces in real-time and convert them into a significant number of triangle meshes, but new meshes will replace old meshes. The only solution to save the entire environment is to scan the entire room once and save the meshes. This approach wasted too much human power and time. It is difficult to save the full indoor environment once. Moreover, when there is any change inside the building, all the meshes need to be rescanned again. The second solution is the developers draw out the entire building structures with CAD software. This approach can approximately get the indoor structure, the accuracy of room structure depends on how good the room plan is.

4.3.2 Bind Location

We need to combine the real world and three-dimensional maps. At first, we need to do is integrate coordinate systems of the map with the real world. The best solution is using Vuforia markers in the real world. This marker can also be founded on three-dimensional maps. The system knows the position value of both image marker in the real world and three-dimensional map, that means the system can use relative positions to the markers for indoor navigation.

4.3.3 Deploy Markers

Indoor navigation system managers are only allowed to deploy the marks, that means only the building workers have the right to use this feature. When one marker needs to be deployed in an exhibition, what the needs to do is drag and drop a marker in the server side. Moreover, an other approach can be used is building workers wearing HoloLens and deploy markers in the real world. A voice command will activate this function. When the users want to deploy markers, they only needs to tap the air in front of HoloLens camera, and the marker will be generated in front of users. If the users are not satisfied with the current marker's location, they can use capture gesture to move the marker by hand when the user release hand, and the movement will stop. When the final position has been decided, the user can give a save command to send all the marker locations to the server side to share with

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[1] https://docs.microsoft.com/en-us/windows/mixed-reality/spatial-mapping-design

other users. For the managers in the building, they have the right to see all the marker has been deployed to make sure there is no overlap on markers. Moreover, for the visitors to the building, they will see this marker when they request to find it. However, they cannot see all the markers. What we also need to be careful is the name of markers. It will be a challenge for Hololens users to write information on that because of the horrible user experience on input. These markers will only register the number of each marker instead of the name. The solution is that all the markers will also appear on the computer side, the manager can use the mouse to tap it and give a name of each marker. So these markers will be saved for the further use for visitors.

4.3.4 Search For Target and Navigate

Visitors could only use the search target function. When visitors have the requirement of getting access to a position in buildings, they can use voice commands to call a panel which contains all the markers in the room. Visitors can use gestures to select the places they want to have a visit. The purpose of using gesture is to prevent the system for recognising speech of other visitors as a command and influence, and it will be better to use gestures for interaction. When the target has been selected, the HoloLens will send a request to the server to find this target. When the target has been found, the system server will generate a pathway from user visitor current location to target. The system server will send user navigator positions in real-time. Moreover, when the HoloLens received navigator position information, an AR object will appear in front of the user and start moving. Visitors need to follow the navigator to the target location.

4.3.5 Navigate Instruction

When the navigator starts moving, the system needs to make sure the users can have a good user experience. A bad user experience makes users get confused and difficult to follow navigator. The navigation system should not be too fast and needs always to keep a range of distance from visitors. For example, when the navigator is too far from the user, it needs to stop until the user gets close enough to the navigator. Moreover, the navigator also needs to make sure it stays in the user's view during navigation. When the user is following the navigator, but the visitor wants to have a look at the watch to checkout time, and the system needs to calculate the is user looking at navigator or not, if the navigator is out of the user's gaze, the navigator needs to be stopped until the visitor look back again. When the navigator is behind the wall, the navigator needs to be highlighted to make sure the users can find them. When visitors arrived target location, the marker of target position will appear to help the user find it. At the same time, the navigator will finish navigation and disappear.

5
Implementation

To make our indoor navigation system work, we designed an application on the Microsoft HoloLens as a client to provide user guide information. We use a PC on the server side. This server side as a workstation which contains the three-dimensional map of the entire third floor of Pleinlaan 9 building. This map contains all the inside context of the building. We use HoloLens to display user interfaces for the navigation system and also provide navigate instructions.

Our indoor navigation needs mainly three steps to be built, and the first step is to generate the entire map of the Pleinlaan 9 third floor and add markers for this room. The second step is to bind the real world with the three-dimensional map in the server side. The third step is to generate a pathway from the user position to the target location which is desired by users.

5.1 Map Generation

To get the entire room of a building, we decided to use a software called pCon planner[1] to draw out the 3-dimensional plan of the entire level of the WISE lab as Figure 5.1 shows. We used the third floor flat map as background, and

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[1] https://pcon-planner.com/en/

add walls and doors on this plan. This map contains good accuracy and can be used to real world well, the size value of rooms in the map is the same as the size of rooms. This feature of the flat map to make sure the accuracy of indoor navigation.

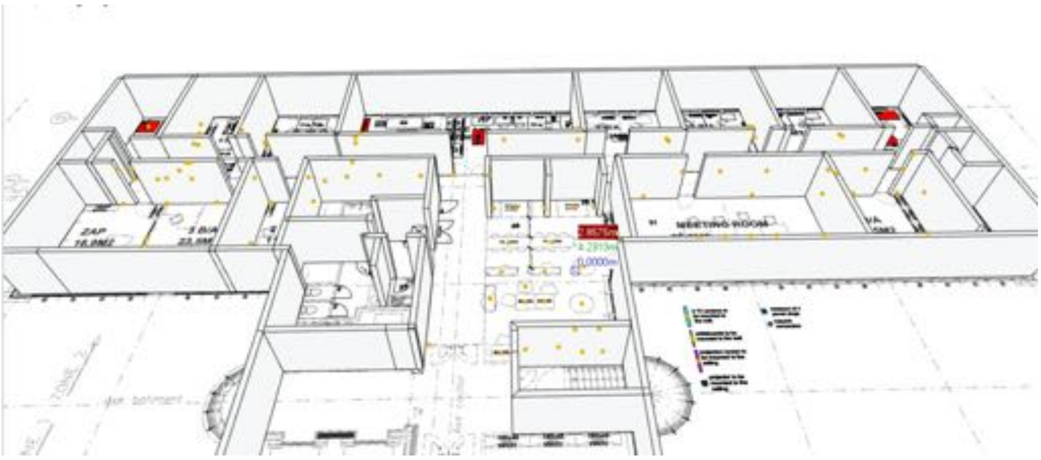

Figure 5.1: Three-dimensional map of WISE Lab

When the room plan software named pCon has generated the map, we export the three-dimension structure of this floor and input the file into Unity game engine for pathway generation. We need to follow the principle that AR navigators cannot pass through the walls, and building managers also need to have the ability to control the accessibility of this building. That means we need to make room segment. The segment software we used is a Unity game engine feature named NavMesh. This feature is widely used for game developing to generate assessable areas for game objects. We used this feature to segment the map into different rooms, and walls isolate each room. The navigator can move in these areas freedom without any blocks. However, each room should be accessible unless the managers closed the accessibility of this room. To connect these rooms, we added the doors into the three-dimension map and reused the NavMesh feature to get a new building segmented map. This map can be mainly dismember the room into three parts. As it is shown in the picture below, the green parts mean users can access the areas, the navigator can get access to all the green areas. Moreover, the areas with red dots stand the places with walls, that means the navigator cannot get into these areas, this approach can make sure the navigator does not pass through the walls. Also, the third part is in blue. This area stands for the emergency exit stairs of this building. These areas cannot be accessed by normal visitors without keys.

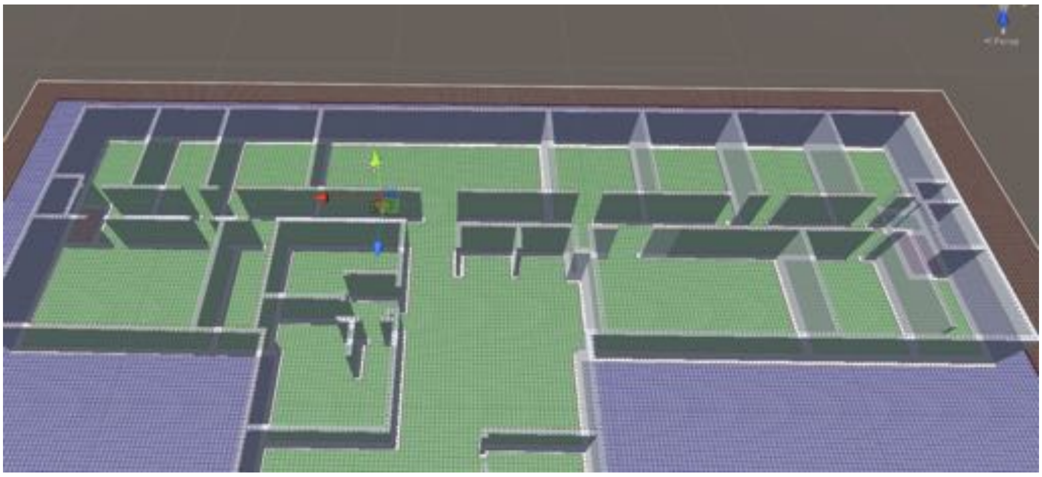

Figure 5.2: Segmented three-dimensional map

5.2 Location Synchronise

When we get the three-dimensional map of the building, the next step is the binding of the room map and HoloLens to unify their coordinate system.

5.2.1 Generate Communication System

At first, we need to make sure the communication between the HoloLens and the PC work well. We make the PC run a server that can connect with all the HoloLens which are used for navigation. We use sockets for communication between server side and client side.

5.2.2 Communicate Data Type

We used JavaScript Object Notation(JSON) to exchange data between the server and client sides. We created a class named command, and this class contains information to be used by the client and server side, the class contains values below:

- command: the server executes the commands. Our command contains match coordination, synchronise anchors and search target position.
- Position: the position can be the current position of user or position of the navigator that has been deployed by users as a spatial anchor.
- Rotation: the rotation can be the current rotation of user or rotation of navigator that has been deployed by users as the spatial anchor.

5.2.3 Binding of Coordinate System

The coordinate system of the HoloLens will change on every new instance of the application. For example, the user at position A opened the navigation application, the coordinate system will regard the position which opened this application as (0,0,0), and the x-axis is always at the direction user is facing to. However, after this application has been closed, and the user currently is standing at position B and reopens the application, the coordinate system and x-axis will be changed.

To bind the three-dimensional map of the server-side and real world which observed by HoloLens we need to find two positions which are found in both the three-dimension map and the real world to stand the same place. We call this position anchor. The server-side anchor should be a game object which contains both rotation and location value in three-dimension map. We post a Vuforia marker in the real world, when the user looks at this Vuforia marker, the HoloLens will recognise this marker and an anchor will appear in front of the Vuforia marker with a fixed position, if the system binds the three-dimensional map of server and real world, both the server and the client will generate an anchor. As is shown Figure 5.3 and Figure 5.4, the anchor of real world and three-dimension map are both in the centre of the connect button. If the system binds these anchors together, that means these anchors of the three-dimensional map on the server side and the real world on the client side at the same place. The coordinate system of the three-dimensional map and the real world also be aligned at the same time, and the scale of three-dimension map will also be scaled same as the real world, the scale rate is according to the distance between the anchor and Vuforia marker of the three-dimensional map.

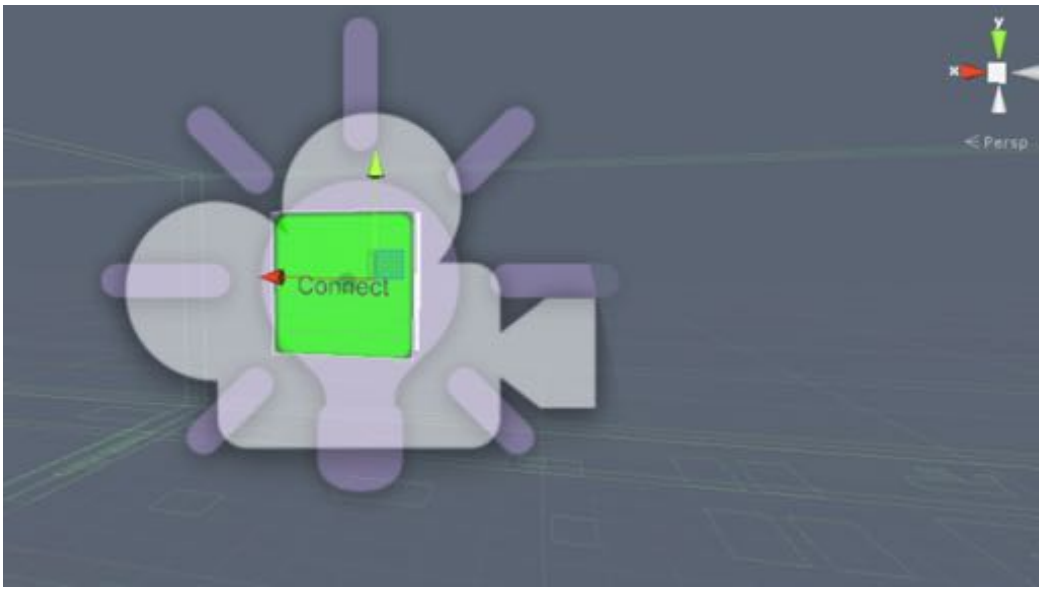

Figure 5.3: Anchor on the three-dimensional map (connect button)

Figure 5.4: Anchor on the real world (the connect button)

5.2.4 Synchronize User and Navigator Movements

The client side needs to send the current location and position to the server in real-time to make sure that the server can always get the latest information about the client to make sure navigate system can always monitor the movement of users. All the movement value of user which be sent to server side will be value relative to the client anchor. On the server side, the system will generate a game object to stand for the HoloLens, as is shown in the Figure 5.5, the paper plane stands for HoloLens, the forward stands for the direction a user is looking at, and all the movements of this user in the real world can correspond to plane movements in three-dimension map. Moreover, this solution also works in server side, when the navigation system needs to share navigator position with a client when the client requests a guide, the server should also send navigator and target marker positions which are relevant the to anchor.

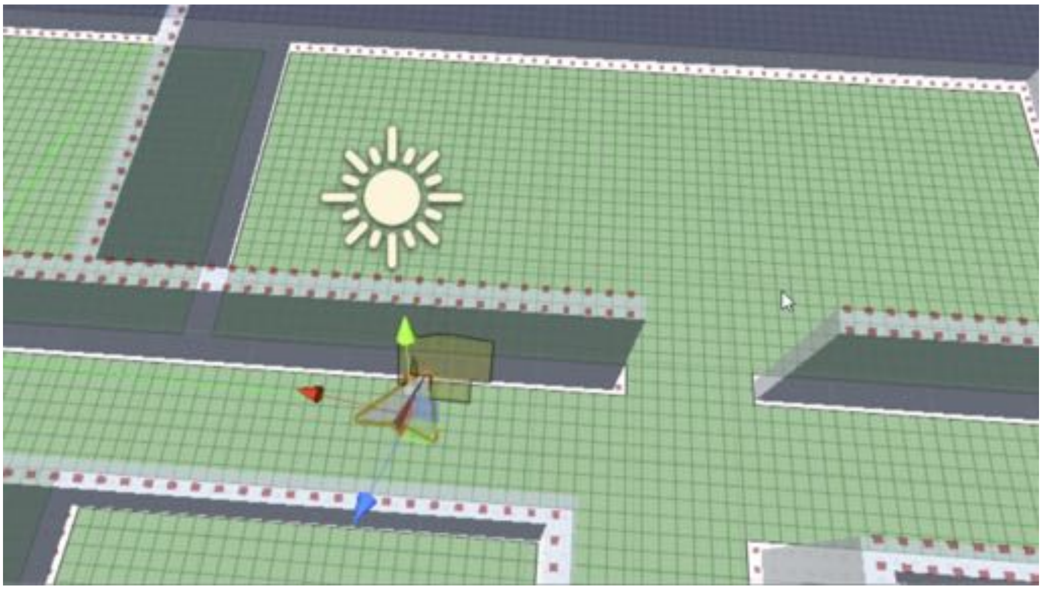

Figure 5.5: Paper plane stands for user in three-dimension map

As is shown in the Figure 5.6, if the system can get the vector from Vuforia object to the user, HoloLens can send this vector to the the server side, and server side will calculate the location of user in server side.

Figure 5.6: Send user movement to server get user movement

5.3 Navigation

When the server side map and client-side map have been synchronised, the user can give a command to search target places. We used a Unity package named A-star pathfinding for pathway generation. When the target marker has been found, a pathway will be calculated out from user to target location. As is shown in Figure 5.7, this pathway is from a user's current position to target position. When the pathway is generated, the navigator on the server side will be generated and go through the pathway. At the same time server will send navigator positions to the client in real-time. Moreover, on the client side, HoloLens will generate a navigator and follow these locations sent by the server. The navigator can avoid obstacles such as walls in three-dimension map. As is seen in Figure 5.8, the spaceship is a navigator on the HoloLens, the position of this navigator in the real world can correspond to the navigator(cylinder) in three-dimension map.

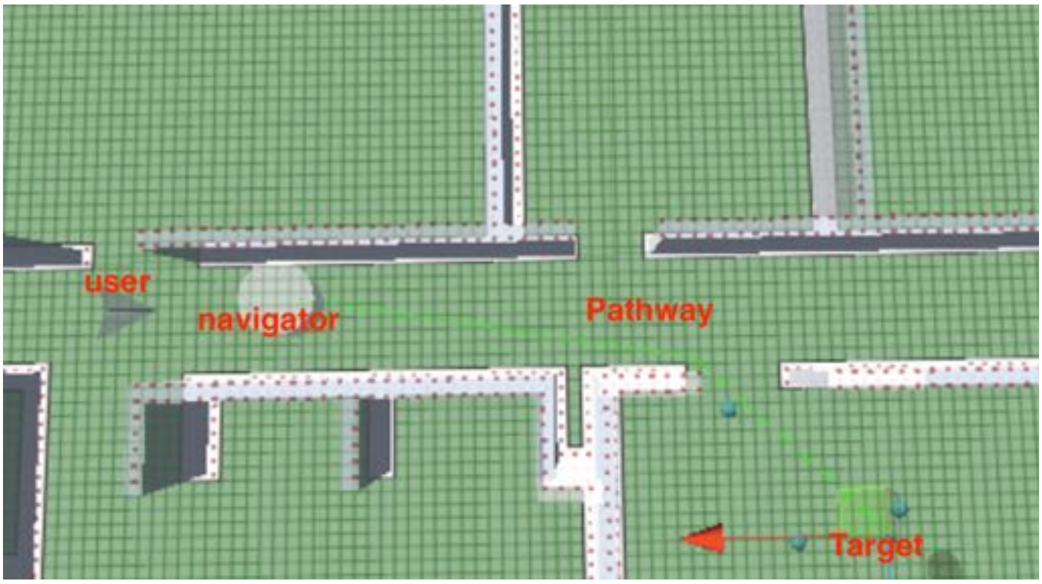

Figure 5.7: Pathway be generated in three-dimension map

Figure 5.8: Navigator in real world

If the navigator is faster than user move speed, and too far from the user, the system will make the navigator stop and wait for the user until the user is close enough to the navigator. According to our experiment the distance to make navigator stop is three meters, and when the user follows the navigator again to decrease the distance to two meters, the system can give user best experience. If the navigator is not on the horizon of the user, we also need to make the navigator stop until user looks at it again. The solution is that the system can calculate the included angle between the forward position of the user gaze and the ray from the user to the navigator. When the included angle is more than sixty degrees, the navigator will stop until the include degree is less than sixty, the navigator will move again.

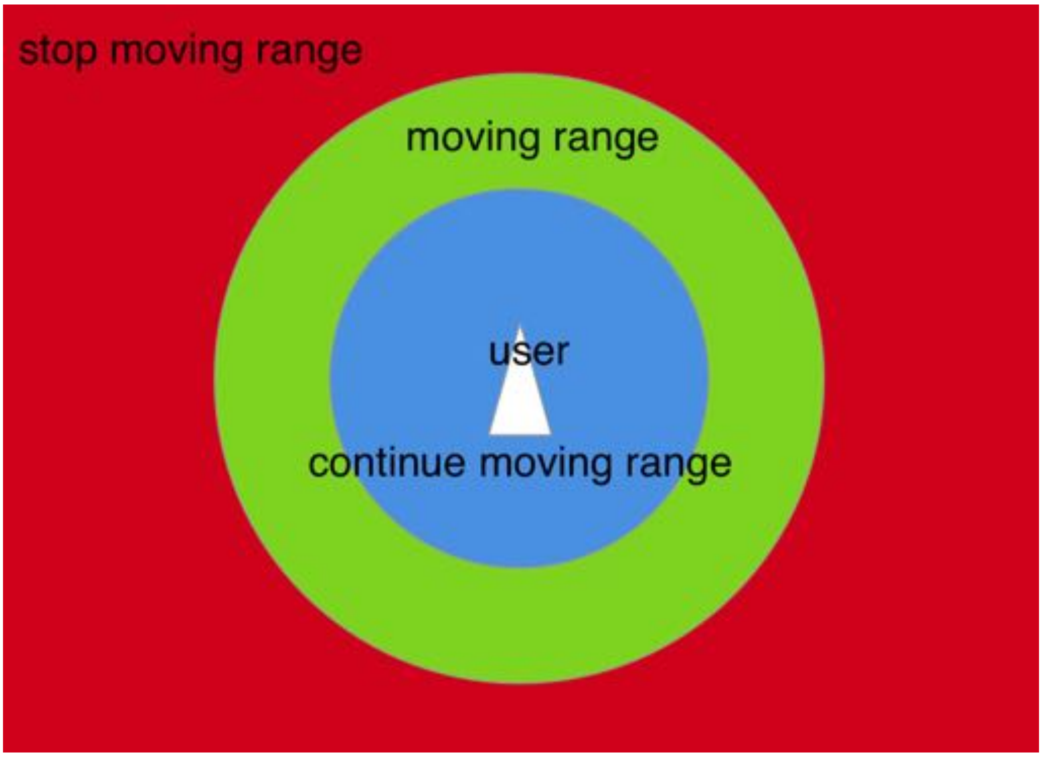

Figure 5.9: Ranges for user to stop moving and continue move

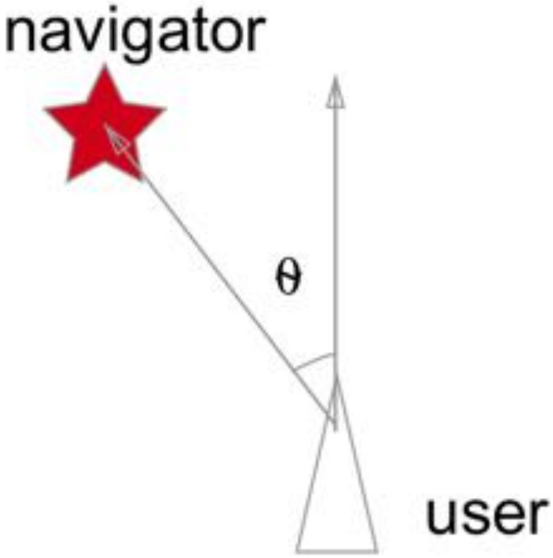

Figure 5.10: Angle for user to stop moving

We also need to take the context in the real world into consideration, without the thinking about context, the navigator can make users confused. For example, when the navigator gets into a room, but the user is outside the room, if the navigator is a real object, these must have occlusion effect between wall and navigator. If the system does not contain this effect, the user will be confused because the user does not know whether the navigator in this room or not. To solve this issue, we need to use the spatial mapping function to detect the room. When the HoloLens connect to the server, the spatial function will be activated, the HoloLens depth camera will scan the context in front of the user and generate a series of invisible surface meshes. The user location will send a ray to the navigator if the mesh is between navigator and use, as is shown in Figure 5.11 the system can detect it and change navigator in client-side another colour to inform the user the navigator is inside room.

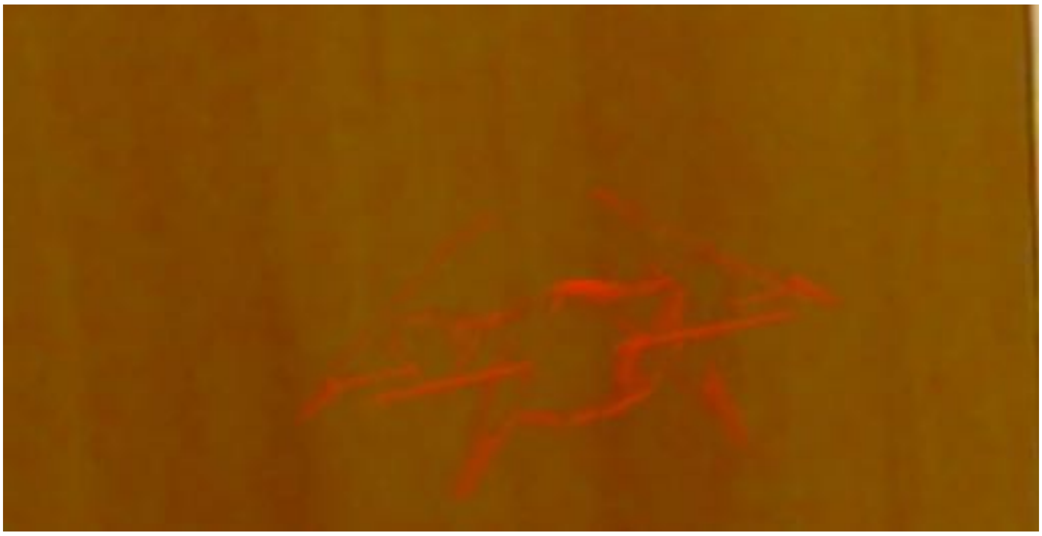

Figure 5.11: Navigator be highlighted when it is behind a wall

Another usage of spatial detection is to correct movement. The IMU sensor cannot always provide system correct movement information. We can also use spatial mapping feature to fix this problem. Spatial mapping can be used to confirm current location and rotation If the movement information of IMU is not correct, the system can recalculate user location with spatial mesh is detected to make sure the system can always get correct movements of users.

When user is close to target position, the system can calculate out distance of user and target location, and according to experiment results, when the distance between target and user less than one meter, and the user is looking at navigator this moment, the navigator will disappear, and target marker will appear to inform user that the target has been found, and navigation will stop.

6

Evaluation

In order to evaluate the accuracy of our solution, we conducted a small lab study. We noticed that there are three factors which can influence the accuracy of our system. The first factor is the speed at which the HoloLens detects the spatial anchors. Another factor is the bias of positions which are calculated on the server side. Moreover, the last one is the error cased by the Vuforia image processing library, which can change the shared reference points between the server side and the HoloLens.

6.1 Study Design

To test the error of navigation system, we need to make study design to test the error of spatial anchor and the error of the communication. During our study we are aiming to measure the distance between the location of the targets inside the HoloLens space against the location of the same targets inside the server side space. we also need to test the error caused by Vuforia.

As we mentioned in the implementation section, the managers need to enter the targets as markers in the three-dimensional map inside server, and when the users give a navigation request, the system will guide them to their desired area. We want find out if manual authoring of the targets can have a better accuracy. Therefore, our study is designed to test the accuracy of both spatial anchors and the manually authored markers on the server side.

We will conduct two studies, and we repeat each fifteen times.

6.1.1 Spatial Anchor Accuracy

The spatial anchors bring errors for indoor navigation. As we know, when the spatial anchor has been deployed, it should always be fixed in one position. However, the position of these anchors will be slightly changed because of the delay of the spatial mapping of the HoloLens. We generate nine world anchors in the real world and send them to the server side as markers. The server will calculate these marker's locations in the its own three-dimensional space and saves these locations. In each repetition of the study we randomly take five markers and when the user has a navigation command, the server will calculate the position of these markers for HoloLens side and transfer the position data to the HoloLens. We need to calculate the distance between the spatial anchors and the position sent by the server. The accuracy is measured by the mean distance of these five markers and the spatial anchors sent by the HoloLens. We will repeat this test fifteen times and get the mean value of each repetition shown in the Figure 6.1. We defined the threshold of 0.6 meters as the acceptable distance for each repetition. From Figure 6.1 we can see that the accuracy rate for the spatial anchor only case is 73.3%.

6.1.2 Manual Authoring Accuracy

Another test we did was the measuring of the distance from markers deployed manually in the server side's three-dimensional space and the spatial anchor in the real world. We first put a series of markers in the three-dimension map, when the server and the HoloLens are connected, the server will calculate the navigation pathway and send it to the HoloLens. The difference of this test from Spatial Anchor error measurement is this test will only considerate the error of Vuforia marker once. Similarly to the test of the spatial anchor accuracy, we generate nine markers in the server side and randomly pick five markers for navigation. The server will receives the spatial anchor locations and calculates the error between them on the server side. We repeat the test fifteen times, and as shown in the Figure 6.1. We consider a threshold of 0.6 meters when the distance is lower than this value, we regard the navigation succeed, otherwise, the navigation is wrong. The accuracy rate is 86.7%.

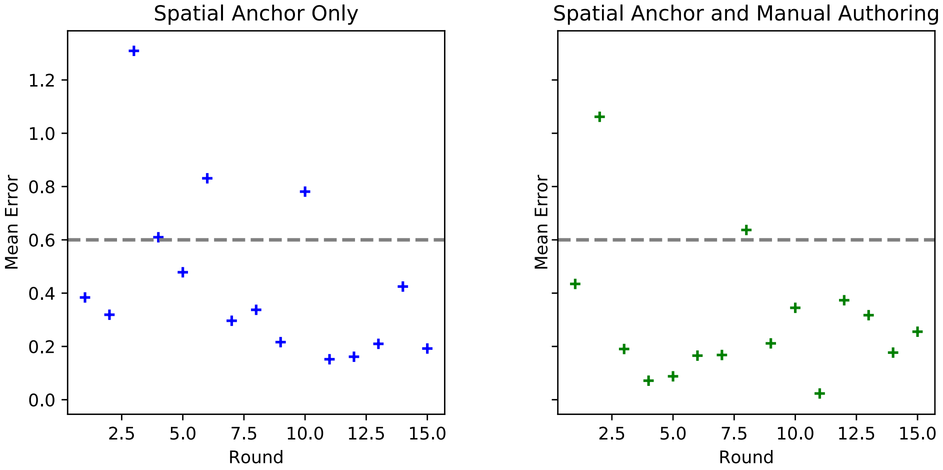

Figure 6.1: Mean errors of two tests

6.2 Analysis of the Results

We noticed from the results that the error rate decreased to half when we use the manual authoring. Manual authoring system only needs to bind reality to the three-dimensional map once, but the spatial anchor needs to bind reality with three-dimension twice, once is sending the spatial anchor position, and another is asking the position value from the server side. We can assume the error mainly comes from the process of detecting the Vuforia markers by the HoloLens. Moreover, to make the navigation system more accurate, we need to make use of manual authoring approach on the server side. In addition, one might say we can improve the accuracy of the system by improving the image processing techniques used during this study, or we can achieve better accuracy by putting the Vuforia marker in place with better light or redesign the Vuforia marker to make the camera detect the marker better. However, these approaches may not always be possible in a real life scenario because of the logistical or technological limitations. This system can work well to find large objects, however, the accuracy will be lower when we need to use the navigation system detecting the objects with small size. One solution for this problem is to place the target markers near the cabinet of these small objects.

7

Conclusion and Future Work

7.1 Future Work

7.1.1 Applications

The indoor navigation solution offered in this thesis is not limited to any specific scenario. For example, in large shopping malls, this indoor navigation system can provide customers some hints regarding the location of their desired items as well as showing them new deals and discounts on their way to their destination. This navigation system can help visitors to find the shops they required. Moreover, this indoor navigation system can also be used in museums to help users finding the exhibitions the user desired, and when the system detected the visitor has arrived, it can display some information in front of the exhibitions and introduce this exhibition in details.

7.1.2 Improvement

This indoor navigation system still has shortcomings which need to be improved. The marker deployment approach should be improved. For the moment the manual authoring is performed inside the Unity editor. That means adding new objects may require the deployment of the server side for each new form of geometry added by the end users. In order to solve this problem, we are planning to add the real-time insertion and transformation of the 3D objects to our server side. Moreover, adding features like the snapping grid to our server side can help our markers being deployed more accurately with a mouse drag and drop.

7.2 Conclusion

7.2.1 Works

In this thesis, we developed an indoor navigation solution for users in different scenarios (for example, inside a museum). At first, we analysed why the GPS cannot be used for the indoor scenario. Then, we analysed what requirements for the indoor navigation system needs to satisfy. After the analysing of indoor navigation requirements, we listed the technologies which are used in recent years for indoor navigation. We made a analyse of these approaches about their accuracy, cost and using scenarios to find some approach that can be used for our navigation system. During our implementation we decide to use the HoloLens as the client side to provide user navigational information, and a computer as a server to calculate pathways for users and send the pathways information to the HoloLens. We simply converted a 2D plan of a the WISE lab into a three-dimensional map of the entire building on the server side to generate pathways. To generate pathways, we used NavMesh to segment the three-dimension map into three parts to make sure the system can find the walls when generating pathways and avoiding making the users to go through the walls, and we use the A^* path-finding algorithm (in form of an already implemented package)on the segmented areas to generate pathways for the navigation. Furthermore, we use the Vuforia marks to bind the three-dimensional map to the real location of the walls and objects. In order to exchange data between the server and the Hololens, we developed a socket communication system to submit the current position of the user to the server side. Moreover, on the server side, the system receives the position and rotation values sent by the HoloLens and transforms the values into position and rotation on the HoloLens. The server side is cross-platform, we simply need to export the server software to runs on Windows, MacOS and Linux operating systems.

The system on the server side can detect the distance and angle between the users and navigator to decide whether the navigator should stop or keep moving towards the target. We also made the server able to detect if the user is closed to the target or not to decide inform them about the exact location of the target at the destination. We designed a simple experiment to measure the accuracy of our solution. The results of our study shows that manually generated targets in the server side will improve the navigation accuracy.

A

Your Appendix

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