3D Visualized Indoor Positioning System

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Abstract

Three-dimensional visualization refers to the process by which graphical content is created using the Three-dimensional software. While working with Three-dimensional visualization, different indoor positioning techniques can be used to detect and track the movement of objects. Combining these two technologies provide the ability to monitor a room and its objects in real time. Positioning is the process of recording the movement of objects or people. Positioning techniques can be used in many different areas such as emergent situations and tracking objects with potential risks as an aid.

It is not self-evident how well this kind of a system would work in the given contexts. To address this, the method has consisted of a literature study focused on existing theories of positioning and different factors that affect the positioning outcome and a case study on positioning systems in a number of existing indoor positioning systems.

The purpose of this project is to present and evaluate a prototype where an indoor positioning system will be combined with a specific platform which works with simple types of hardware signals to generate three-dimensional models. The goal is to present a system that will have the ability to be used without any infrastructure or external hardware. Different indoor positioning systems will be analyzed as well as their use in various scenarios. This thesis evaluates various technical choices, and provides an overview of some of the existing wireless indoor positioning solutions and the theory and methods used, before describing the case study, including the development process, problems faced, the result, and the experimental testing results. In conclusion, the thesis presents a prototype which is validated to fulfill the basic expectation of a three-dimensional visualized indoor positioning system.

Keywords- Indoor positioning, Magnetic positioning, Signal transportation, Three-dimensional Visualization
Sammanfattning


Det är inte självklart hur bra ett sådant system skulle fungera i de givna sammanhangen. För att ta itu med detta, har metoden bestått av en litteraturstudie inriktad på befintliga teorier om positionering, olika faktorer som påverkar positionerings resultatet samt en fallstudie om positioneringssystem i ett antal befintliga inomhus positioneringssystem.


Nyckelord- Inomhuspositionering, Magnetisk positionering, Signal transportation, Tredimensionell visualisering.
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1. Introduction

3D techniques have been a rapidly developing topic in last decades, the current applications in this area are not only restricted within virtuality but also extends to the reality. Based on the background of a trend in nowadays society to use the 3D visualization method in adapting to existing problems, the thesis introduces the potentiality of how to use 3D visualization to monitor real-life objects in the indoor environment.

1.1 Background

The thesis includes the research in positioning data sending solutions and the data transportation from real objects to the 3D virtual environment.

Considering an emergency situation in which many positioning systems are not able to work properly, for example in a building on fire, due to heavy smoke, loss of electricity and building collapse. In a situation like this, the firefighters lose their sense of direction and cannot see their surroundings. Given that indoor positioning in a room full of smoke is tough and that most of the existing positioning systems rely on external hardware and infrastructures, a system that is not dependent on any kind of infrastructure is preferred. Meanwhile having a 3D display of the surroundings for a more detailed view of the environment rather than a flat perspective[1], so that objects which have been moved around or collapsed, high edges or height differences can be detected and shown on a 3D display. These kinds of detailed information cannot be provided with a 2D model. In order to implement such a system and to be able to detect if certain objects have changed position, some kind of detection tag or sensor is needed to be able to obtain the objects current position.

If an indoor environment with all the objects inside can be displayed in real time, it will not be a problem for firefighters to navigate themselves through a room in a situation where the room is full of smoke. There also will not be any obstacles in their way that they do not know about, for example, if a doorway is blocked by a bookshelf that has fallen. Having a 3D display of a room and its objects in real time can also be useful in a situation where rescue robots are used to examine the room.

Most of the current tracking devices typically rely on Wi-Fi access points, GPS signals which are not reliable indoors, or expensive, high-quality sensors[2]. By examining the requirement of specific scenarios, it was concluded that utilization of smartphone sensors would be the optimal choice for the designed prototype in this research.

3D Graphic

With the rapid development of computer technology especially in computer graphics, the three-dimensional display becomes the mainstream which meets the need for the more stereoscopic way to convey the information in various fields[1]. In computer
technology, 3D computer graphic is defined as the process using 3D software-based techniques to create graphical contents[3]. The graphical content created during the modeling and rendering, in essence, is the mathematical representation in the three-dimensional space[4]. The special feature of providing the depth information of visual object makes the 3D graphic more competitive than traditional 2D graphical displays.

In 3D computer graphics, every single shape is displayed by the wireframe. As the name suggested, the wireframe is shown in form of wires. From the geometric perspective, wires have the ability to present the depth and volume of complex 3D surfaces in 2D perspective[5]. To construct the complex surface of 3D models, the large number of tiny shapes are required. From the visual perspective, several factors of the surface are concerned with creating a surface. The color is the most intuitive factor that is needed for a surface. The digital additive color model is set and mixed for giving different colors to the shapes and thus presenting a colored 3D model. Besides the color, the texture and reflection are also able to influence the visual sense. The suitable texture and reflection of the surface will contribute to the sense of realistic of the model. Shading and shadow is usually a part of post-production but necessary to present the feeling of weight and solidity of the model.

There is a large variety of 3D graphic creating processes[4]. In general, the artists manually construct the models by controlling the size and amount of basic shapes as well as configuring the color, texture, and shades. The accomplishment of the 3D graphics normally requires creators to have the ability to observe the real objects appearance features. However, it is necessary to assume the possibility that users do not possess the specialty of artistic modeling for many 3D related applications nowadays. Thus, the process of appearance capturing can also be done by the automatic computing. This allows the 3D graphics not restrict in the art and design fields but opens up the large potentiality for various areas using computer vision.

Due to the great potential of development, 3D visualization can be considered as one of the popular options for producing high-quality digital content[1]. Based on its advantage, the application of 3D graphic can extend to a large scale of different fields and industries, including medical, education and navigation instead of being limited to media and entertainment usage. Indoor positioning is one of the potential cases that 3D graphic can be applied to. Using the 3D modeling and rendering technology into the indoor positioning system is a channel for the positioning system to reach to users from different backgrounds through the more detailed and realistic visual experience. Visual sense is one of the important ways to access information. Three-dimensional perspective presents the vision with depth and volume making the accessed information more accurate.
**Indoor Positioning**

Today, there are numerous different techniques for implementing an indoor positioning system, such as positioning using Wi-Fi, Bluetooth, and magnetic fields. Yet, the only standard solution for positioning is the global positioning system (GPS), and it is not applicable indoors[6]. There are many real-world applications that depend on positioning systems. It could, for example, be used for the location of objects in a room, location of medical equipment in a hospital, the location of products in a warehouse or finding tagged maintenance tools and objects in a building or a room[7]. A large number of services are based on knowing where something is, which refers to location-based services. These services can be divided into different categories.

There are a few different categories that location-based services could be divided into[8]:

- **Navigation**: Indoor navigation in large buildings or in-car navigation.

- **Location-sensitive information**: Distribution of information to mobile devices based on their location, for example, mobile advertising, weathercast services or electronic museum guides which gives the visitor information about the artifacts that are close to him/her.

- **Tracking**: Car tracking, asset tracking, tracking of expensive equipment or tracking of objects in a warehouse, the user/object of interest has to carry a specific tag or badge that allows the sensor network to track the position.

- **Directory services**: Provides the ability to search for a product or a service that has a specific location, usually identified by name instead of an address.

- **Emergency services**: A mobile users location is revealed to the emergency service (ambulance, police and so on) or tracking firemen inside a building.

In order to be able to locate an object in a specific environment, an underlying positioning system is needed. Such a system can provide two kinds of information: physical position and symbolic location. Positions are physical and it usually refers to a point in a specified 2D or 3D space[2]. The positions are expressed in coordinates (x,y,z) while locations are symbolic and are expressed in natural language[9]. A system that provides physical positions can usually be augmented to provide corresponding symbolic locations, which means that it is defined by the assigned label[10].

There are a variety of applications where three-dimensional modeling of indoor environment could be useful, such as mapping of a hazardous environment. To construct these models manually can be time-consuming. Therefore, automated 3D
modeling is preferred. Modeling and positioning in indoor environments have significant challenges, the main challenge being the absence of a standard system for indoor positioning.

1.2 Problem definition

Based on the background stated in the section above, it can be observed that there is a lack of large-scale deployments for navigating and positioning in indoor environments as outdoor environments which are dominated by the GPS technology. Many technologies have been developed to provide the location of mobile devices or objects in an indoor environment. However, emergency situations have particular characteristics, such as smoke or blackout that can reduce visibility and make some of the current indoor positioning systems useless.

In recent decades, an increasing number of researches and innovations focusing on implementing indoor positioning technologies are undertaken in both academia and industry. In the meantime, a rising trend of 3D virtuality opens up a new window for a new way of information presentation to adapt to a wider range of users and industries.

To combine the 3D virtuality with the indoor positioning system will provide a more diversified potentiality of innovation and application in real life situation. In this context, the thesis work will answer the following problem:

How to construct an indoor positioning system that presents the 3D visualized location information?

1.3 Purpose

The purpose of the thesis is to implement an experimental system discussing how an indoor positioning system that provides the 3D display of location information can be built. Implementing such a prototype is also expected to show the possibility of 3D graphic and interactive technology in adaptation to presenting visualized information. Also, anyone developing a similar system will learn from the conceptual reasoning and decisions.

The work explains and evaluates various factors involved in the design and implementation of the indoor positioning system through the understanding on the general process of constructing the system from hardware sensors to visualization in three-dimension.

By implementing a prototype and evaluating the 3D visualized indoor positioning system, the basis for the future development of potential applications using visualized technology system is provided.
1.4 Goal

The thesis aims to construct a practical simulation of an indoor positioning system which presents the location information through 3D visualization. The simulation is implemented as a working program with the function of conducting a 3D display according to the signal sent from the devices on real objects. The 3D graphic shows the information about the location of targeted objects visually in reference to the indoor environment. Through both the theoretical and practical analysis on various factors, the project has the potential contribution to the current researches in the field of both 3D visualized information and indoor positioning and introduce new possibilities for a combined system.

1.4.1 Benefits, Ethics and Sustainability

The combination of a positioning system with 3D modeling of an indoor environment could be very useful in different situations, for example in emergency situations where vision is very limited, whether it is a room full of smoke or a dark room.

In emergency situations, for example in a building on fire, many positioning systems are not able to work properly due to the harsh circumstances. When the firefighters lose their sense of direction, they get put under danger and psychological pressure. Knowing in detail what the objects in the surroundings are and how they are placed could be the difference between life and death under those circumstances.

Given that indoor positioning for firefighters is tough and that most of the existing positioning systems rely on external hardware and infrastructure, in a situation like this, a system that is not dependent on any kind of infrastructure is preferred.

As described in the example above, the ability to cope with various emergent situation makes this system capable of reducing the rate of death and injuries from risks. This has the significant contribution to the global health and wellbeing target. Meanwhile, the flexible and convenient usability leads to a safe, resilient and sustainable living environment, referring to the Sustainable Development Goal 3 and 11 proposed by United Nation[11].

1.5 Methods

Methods and methodologies are essential for setting up and steering the work to accomplish legitimate outcomes. The research methods are procedures that guarantee the quality of the results of the research and project[12]. The methods that are applied are used as guidelines to carry out the research project, they can be categorized into quantitative or qualitative research methods. Quantitative research methods are used if the goal of the project is about proving or testing, while qualitative research methods focus on studying a phenomenon in order to summarize and create ideas upon that[12]. The main data collection method used for a
quantitative research is experiments and case study for is the most commonly used for a qualitative research. Case study, questionnaire and observation methods are included in both research methods.

There are different research methods, and methodologies and these are divided into two categories, the ones that work well for quantitative and the ones that are suitable for qualitative methods.

In general, the research methods applied in this thesis aims at both quantitative and qualitative research[13]. This is called triangulation and is used to ensure the correctness of the results by increasing the validity of the results.

The goals of qualitative research are getting understanding about specific cases and extending findings to similar situations[14], while the purpose of the proposed problem within this thesis is to explore the potentiality of the 3D visualization technology in constructing the specific positioning system in practice. The qualitative research methods are sufficient for understanding the various concepts, thoughts and existed technologies for designing and developing a new system in the engineering field. Quantitative methods aim to prove a phenomenon by experiments or testing of a system and was used to investigate the performance of the systems.

Research approaches are used in order to establish whether something is true or false[12], they can be divided into two main approaches, quantitative research approach which is informed by deductive logic and qualitative research approach which is informed by inductive logic. There is also one approach that is somewhere in between, called abductive approach. In an inductive approach, potential understandings of a phenomenon are obtained from the data, as such hypotheses are formed, following the collection and analysis of the data to gain the understanding of the phenomenon. The data is usually collected and analyzed with qualitative methods.

In the deductive approach[12], the research usually starts with hypotheses and then collecting data that can be used to verify or falsify that hypothesis. The theories or hypotheses are tested by using quantitative methods with large datasets. Abductive approach uses both previous approaches in order to draw a conclusion[12]. This approach starts with a hypothesis, and then, conclusions are drawn through an incomplete set of data or observations. For this thesis, a deductive approach was used for the system where experiments and case study were used to collect data in order to gain prove a phenomenon. Experiments go hand in hand with experimental research methods, these methods are used to investigate the performance of the system and to establish relationships between variables. It can manipulate a variable in order to see how the changes affect other system variables.
Positivism[12] is used as a philosophical assumption, positivism assumes that the reality is objective and is suited for projects that are of experimental and testing character.

The way of organizing work of development is another concern. The clear logic and milestones are required during the design and to present an implementation of the experimental system. An agile method is based on incremental and iterative working during the process of software development. Hence, project methods like Scrum are popular for an efficient workflow[15]. On the other hand, the waterfall method which also refers to the traditional method is also widely used in the development process. It is a linear approach which has distinct stages of development. This method provides a full scope understanding of the development and an intuitive view of the progress during development.

1.6 Delimitations

In terms of potential technologies developed to adapt to the indoor positioning solution, the range of the project can be wide. The project will mainly focus on the general technical factors to be considered in a complete visualized indoor positioning system. Although several different technologies will be proposed in discussing the part of signal sending end for capturing position data, no further comparison or evaluation is emphasized in this thesis.

The prototype was constructed to test the validity of general factors and working principles. Thus the capacity, accuracy, and durability of certain techniques are not a part of the consideration, but it will be mentioned for further discussion.

There is a broad range of different positioning systems that have been implemented by other researchers and companies, different solutions and techniques are suited for certain environments, and different applications may require different types of location information. In this project, the focus of the prototype was narrowed down to getting the position information as latitude and longitude (x,y) the prototype will be built according to our requirements, available assets for the project and environmental aspects.

One aspect of this research has been to investigate how different technologies and methods have been utilized and how they perform. But this task was not easy due to the limit amount of information about algorithms and hardware revealed and shared by companies.
1.7 Outline

The outline of this thesis consists of the following:

Chapter 2 presents fundamental background information about general indoor positioning systems and 3D display techniques. It will also discuss different positioning technologies in detail along with some estimation techniques and measurement methods used by the different indoor positioning technologies.

Chapter 3 presents descriptions and reasoning behind methods and scientific methodologies used during the project. How the prototype is planned to be developed is presented as well.

Chapter 4 details the entire development process behind the prototype, explaining choices made and problems faced.

Chapter 5 presents and briefly describes the results of the project, which also discusses the validity and reliability of the methods and results, before reaching a conclusion to the problem.

Chapter 6 presents the conclusions drawn from the project results and evaluations.

2. Theoretic Background

Localization of objects indoors is important to many services. In recent years, there has been a rapid growth of wireless positioning systems and wireless technologies are being used in a lot of different applications, such as industrial, medical and public safety applications, tracking and guiding are some examples of these areas[16].

One main goal of positioning systems is to provide a clear representation of the location information. Examining the current positioning and navigation fields, vision-based methods are widely implemented and dominate the various applications of positioning systems. The vision system is an important channel for human to access and process the external information[17]. Therefore, besides the discussion on the development of positioning technology, the visual representation becomes another noticeable part of the practical positioning systems[2].

2.1 Information visualization

Visual representation is regarded as a transformation between descriptive information and visible concepts[17]. It is a process of taking the complex or unstructured information and interpreting it in a way that the one can intuitively receive and comprehend[18]. For achieving the purpose of providing visible information in a practical way, it is necessary to collect the information and unpack
all the elements[17]. It is crucial to understand the usage of visualization and the user groups that are facing to. This provides the criteria for selecting and deciphering the effective information to users. Another consideration of the visualization process is to find the suitable form of visualization[3]. The growing popularity of virtual reality in nowadays shows that the immersive and interactive visual experience in the 3D environment will provide an easier for receiving and processing information than the plain descriptive graphic[4]. Meanwhile, the representation of an indoor environment requires to show more details comparing to the outdoor scenario. Based on all of these, 3D representation is proposed in this thesis.

### 2.2 Indoor positioning

Nowadays, there are many different positioning technologies that can be used for determining the position of people, objects or mobile devices. Different applications provide different levels of accuracy and can be used in different situations and environments. The most known and used positioning system is the GPS[19], this system provides high accuracy positioning outdoors but is not applicable in indoor environments since the GPS signals are obstructed[19]. For indoor positioning, alternative systems such as Wi-Fi-based positioning systems, inertial navigation systems and positioning systems based on magnetic field are used due to their specific characteristics[20]. This chapter will provide an overview of the common indoor positioning technologies from fundamentals, system requirements and positioning performance.

The shortcomings of indoor positioning systems are usually related to the difficulty of general deployment in a wide range, either low accuracy or expensive hardware can be the obstacle. To find the most effective solution, one usually has to make a trade-off between performance and costs of the system.[21]

#### 2.2.1 Absolute vs relative positioning

Positioning systems are divided into two categories, absolute positioning, and relative positioning. An absolute position uses a shared reference grid for all located objects and is estimated by using external devices, such as beacons, tags, landmarks and so on[1]. For the estimation of the absolute position in outdoor environments, GPS is the most used system, but as mentioned before, this technique is not suited for indoor environments.

Various positioning systems have been developed in order to use an absolute positioning system indoors, systems based on Bluetooth, Wi-Fi and ultrasonic, these are all systems that need to be installed in the area where the positioning system is serviced.
In a relative positioning system, on the other hand, each object can have its own frame of reference, and it does not require any infrastructure. The reason is that relative positioning sensors, such as inertial sensors are installed in the mobile device. But the drawback of relative positioning systems is that they can suffer from errors when the position is calculated.

### 2.3 Positioning techniques

As mentioned before, there are different wireless technologies and solutions that could be used for indoor positioning, depending on which type of communication they are based on. The most commonly used techniques are the ones that are based on infrared light (IR), radio transmission (RF), ultrasound, inertial navigation system (INS), Wireless Local Area Network and magnetic fields. Different applications may need different types of location information, so there will be various solutions depending on the application scenario[22]. These technologies are classified based on; 1) the method of determining location, the usage of different types of measurement of the signal, such as Time Of Arrival (TOA), angle (AOA), received signal strength (RSS); 2) the wireless technology used to communicate with different types devices, for example infrared light, radio frequency and inertial navigation system and; 3) and estimation methods, like trilateration and fingerprinting. In the next section, a review of some technologies will be provided, as well as some of the measurement methods and estimation methods used in these technologies. However, these measurement methods have various disadvantages while used in an indoor environment. For each of them, there need to be an infrastructure installed in the environment, consisting of transmitters and receivers, furthermore, in order for TOA to be used there must exist an accurate way of measuring time, a small time error will result in a large error in the distance calculation. The RSS approach is useful indoors but needs a radio infrastructure, and it will decrease in accuracy with obstacles in the environment affecting the RSS, such as walls or microwave ovens and cause multipath or shadowing issues. To be able to decide whether a certain technology is suitable for a certain situation, an investigation of different positioning systems is needed[20].

Various positioning systems are used to estimate the position of a mobile device in both outdoor and indoor environments. There are several algorithms and techniques that exist for obtaining position information based on signal measurement or properties. The algorithms are used to translate recorded signal properties into distances and angles in order to calculate the position of the target[23]. An indoor wireless positioning system consists of at least two separate hardware components: a signal transmitter and a measuring unit/receiver.

Different positioning systems use different types of signals as references for the location system. Inertial systems use the direction and acceleration of a moving object to get its current position. Magnetic techniques use the disturbance on the magnetic
field of the Earth inside buildings, the disturbance is caused by structural steel, and it is unique in each building position. Then there are optical systems that use photos, known markers or lights as references to positioning. Techniques based on Radio signals compute the radio wave travel time or use the radio signal strength (RSS) to perform the tracking. Signals like Ultra-Wideband (UWB), ZigBee or Wi-Fi can be used. Similarly, ultrasonic techniques use sound wave travel time as the location system reference[19].

2.4 Measurement methods

To be able to use signal properties for indoor positioning, the right measurement method is needed. Measurement methods are related to how the signal is used in order to obtain the tracked devices position. Measurement methods can be used to estimate the angle of an incoming signal or the distance to the source of a received signal[24]. In this context, the measurement and interpretation of signals have a significant dependency on the different transported signal types.

There are a couple of different measurements used to determine the position of a mobile device. To be able to use radio signal properties for the purpose of indoor positioning, a suitable measurement method is needed. Signal properties are geometrical parameters that consist of metrics such as angle, distance and signal strength to measure the position of an object using calculations[25]. A measurement method can be used to estimate the distance between the transmitter and the signal receiver or to estimate the angle of an incoming signal.

2.5 Estimation techniques

Indoor position estimation techniques can be divided into two different approaches. Propagation approach, where the position is calculated by estimating the distance to various reference points, and the fingerprinting approach where a location is uniquely identified by certain signal characteristics. Estimation methods estimate the position based on the information that is provided by the measurement method[20].

There are two commonly used estimation methods for calculating the distance between receiver and transmitter, trilateration and triangulation, and they can use different signal properties for this cause. In this thesis, trilateration will be discussed since it is more suited for the indoor position.

The main estimation methods that are used for estimating the position of indoor mobile objects with Wi-Fi and magnetic positioning are fingerprinting and trilateration.
2.5.1 Trilateration

Trilateration calculates the position of an object by measuring its distance from access points placed in fixed positions with known coordinates by using either Time Of Arrival or RSS[26]. In indoor positioning, the coordinates of the access points are held as fixed nodes. A database is also needed for storing the location of the access points, this includes the coordinates of the access points and the unique Media Access Control address for each of the access points. The distances and the known coordinates are used in a trilateration algorithm to calculate the coordinates of the unknown object. The propagation time or RSSI between the device and the AP is calculated in order to determine the radius from the AP on which the device could be located. This is done by three APs resulting in three spheres. The position of the device is then determined by observing the intersection of the three radiiuses[2]. Trilateration needs to at least use three known positioned access points, as shown in Fig.3. It can either be three known objects and one transmitter or the other way around[26].

Trilateration prefers a line-of-sight environment. Due to the fact that obstacles in the environment will cause signal attenuation, there will be many factors affecting the signal strength of radio signals. This will make it very difficult to estimate accurate distances based on RSS measurements[19].

The position of the device can also be determined by using the Time Of Arrival (TOA) to measure the time it takes for a signal to arrive at the access point[27]. This method will result in high accuracy, but the hardware is very complex and the accuracy depends heavily on environmental conditions. Therefore, it is more suited for outdoor positioning.

![Figure 1. This figure shows the position estimation using the intersection point of three receivers estimated distances.](image)
2.5.2 Fingerprinting

In fingerprinting, the target area is divided on a grid and signals at each grid cell are captured, forming a map of signals, this map is used to perform positioning.

The fingerprinting technique has been used for indoor positioning for quite a few years[19]. The advantage of this estimation method is that it can use existing WLAN infrastructures or other network environments and has the potential to estimate the position of a mobile device very accurately without relying on the placement of the access points. Since it can handle the Line Of Sight problem, it is more suited for indoor positioning compared with other techniques like TOA[27]. It is also easy to deploy and can work with any existing WLAN infrastructure to determine the position of the mobile device.

The fingerprinting method is more suitable for indoor positioning thus it is selected for our project. The idea of this approach is to obtain the location of the object of interest (OOI) by comparing received information from the OOI with data in a pre-recorded database of known resource-location information[28]. The location is identified by using measurement methods. The measurements are stored in a database with their corresponding location to create a map of the radio properties at different locations. The locations that make up the radio map are often referred to as reference points. The idea of fingerprinting is to collect information from a scene or observation and then estimate the position of an object by comparing the collected information with the one in an existing database[7][22].

The fingerprinting method can be divided into two phases when using Wi-Fi systems, the calibration phase and the positioning phase[26][27].

Calibration Phase

The calibration phase includes several procedures that are required for setting up a positioning system based on fingerprints[16]. It consists of collecting data, creating the radio map and creating the database. The radio map is created by setting up reference points in the area of interest and dividing it into sub-areas. To provide the possibility of referring to certain points in the indoor area, a grid and a coordinate system are applied to it. This grid will represent the radio map. These grid points are computed at different locations on the map. After the radio map is created, a unique identification, represented by the id of the access points together with the corresponding RSS is given to each reference point. The combination of different paths that the signals from the access points can take due to various distances and obstacles in the environment will provide each reference point with a unique identification, this identification is referred to as a fingerprint[6].

Each reference point has a list of RSSI values for surrounding access points. Moreover, the respective position information and signal strengths from the different locations
are collected for position estimation purposes. These fingerprints are embedded in a vector that is stored in a database together with its corresponding coordinate[7].

**Positioning Phase**
In the positioning phase, the collected position information is used to compute the position of the object. When the user enters the radio map, the device will start collecting RSS from the access points. This collected vector of name or ids together with RSSs is then compared with all the records in the database. The most commonly used technique for generating a radio map is Wi-Fi, Bluetooth is also sometimes used. But to achieve higher accuracy, a combination of technologies can be used in order to get more parameters that will contribute to the uniqueness of a reference point.

### 2.6 Magnetic fingerprinting

Unlike Wi-Fi based fingerprinting that combine the RSS from multiple APs, a magnetic fingerprint consists of the magnetic field and reference points. A magnetic field fingerprint usually consists of four components: a three-axis vector x, y, z-axes from the smartphone and magnetic field readings, calculated by the first three elements[31].

According to studies[29][30], magnetic fingerprints may not be unique in a large indoor space, which will lead to large localization errors. To solve this problem and improve accuracy, most of the existing works have implemented Monte Carlo Localization algorithm. As with the Wi-Fi fingerprinting system, the MF fingerprinting system can also be divided into two phases:

- **Calibration phase (Offline phase):** By using a mobile phone or a magnetometer for a short amount of time on certain preset positions, magnetic field values are collected and stored as reference points[34].

- **Positioning phase (Online phase):** The online information is collected from reference points of the pre-built dataset. By using the matching algorithm, the exact location will be estimated according to the most similar to the target signal[35].

### 2.7 Positioning Systems

Many positioning systems are used to estimate the position of a device in both indoor and outdoor environments, some of the commonly used positioning systems are introduced below.
2.7.1 Magnetic Positioning
An indoor positioning system that has received less attention and was used in this project is magnetic positioning. This method is based on the magnetic field of the Earth and the compass. Magnetic positioning system involves the use of magnetic signals for position determination within a magnetic field. There have been many studies and researches concerning this area, the most recent studies are based on using magnetic fingerprints.

Magnetic positioning can both be used as a separate technology and combined with an existing Wi-Fi infrastructure[36]. While being integrated with Wi-Fi, an initial position can be obtained by using Wi-Fi-RSSI fingerprints. This type of magnetic positioning measures and estimates the absolute position without any dependency on infrastructure and with fewer errors[37].

When using wireless communication, there are several factors that need to be taken into consideration due to the impact they have on the signals on their way from the transmitter to the receiver, for example, obstacles or other devices that will affect the signal. With magnetic positioning, refraction can occur. Refraction refers to the phenomenon when a wave changes its direction due to changes in its speed[2]. Indoors, there are structures like pillars, steel structures, and fixed large objects that the geomagnetic field is refracted by[30][33]. As a result of this refraction, a magnetic field map can be obtained and used in various methods.

2.7.2 Global Positioning System (GPS)
GPS is the most commonly used system for outdoor environments but it cannot be implemented in indoor environments due to obstruction of the GPS signals. Most of the location-based systems use GPS to determine the current position, but even though it is an inexpensive and accurate method, it has a drawback.

Figure 2. GPS vs. IPS[39]
A common GPS receiver requires line of sight to at least four satellites in order for it to function correctly[8], and therefore it will only work outdoors. The positioning information inside building presented by GPS is not detailed enough as shown in Figure 2. In this situation, other techniques need to be explored in order to achieve positioning capabilities for indoor environments.

### 2.8 Positioning Using Smartphone Technology

Since the smartphones have developed and are equipped with more different built-in sensors, tracking and localization systems will most likely evolve towards systems that can utilize those sensors and merge the information that is provided by the sensors in the smartphones.

These various built-in sensors in smartphones were originally designed for communication and entertainment, but nowadays they have been adapted for Location Based Systems, which have given the use of smartphones an important role for indoor positioning. Right now, GPS technology has been well combined with smartphones and its positioning performance is well suited for outdoor environments, but due to multipath effects and attenuation of GPS signals, it cannot work properly in indoor environments. So in order to address this issue, other built-in sensors are expected to play an important role in indoor positioning.

Most of the mobiles today are equipped with inertial sensors that are capable of reading the state of position and the motion of the device. These sensors can create a three-dimensional view of a location by measuring the direction, speed, and height above sea level[40].

There are some sensors that are worth mentioning due to their relevance to this thesis. The accelerometer, which measures the acceleration of an object, the gyroscope which can sense orientation and the magnetometer, which reads the magnetic field strength and direction surrounding the device. [35][36]

**Accelerometer**

The purpose of the accelerometer is to measure acceleration forces. It measures the applied force while moving. A non-constant movement will lead to an acceleration by applying a force on the accelerometer, and it will make a three-dimensional detection of the force changes. This data can be gathered as three values, in x, y, and z-axis.

**Gyroscope**

The gyroscope works based on the principles of angular momentum, similar to the momentum that a stone flying through the air has. This means that the gyroscope will prevent any outer force that is applied to change its orientation by applying a force
equal to the outer one. The orientation can be measured by measuring the preventing force.

**Magnetometer**
Most smartphones have a built-in magnetometer. An example of an application where a magnetometer is used is the compass. In that case, it is used to read the magnetic field of the Earth and use it to find the direction of north. The magnetic field of the Earth gets disturbed by objects in the environment, and since the magnetometer in a smartphone is very sensitive, the readings can get disturbed by anomalies in the magnetic field, such as walls or electrical wiring. This magnetometer can be used to get the latitude and longitude of a device in order to infer its current position inside a building.

### 2.9 Other positioning systems
A number of different systems have been investigated for their potential use and capability of the indoor positioning field, such as Bluetooth, Radio Frequency Identification (RFID) and infrared light. Bluetooth technology is commonly used for short-range wireless communications, but this kind of solution requires beacons or other equipment[43], RFID is a generic term to describe a wireless system that uses radio waves to transmit identity of an object, RFID readers need dense implementation due to their limited range, they also require accurate tag positioning and are complicated to implement. Systems that are based on infrared light are useful in indoor environments, but the fact that infrared cannot penetrate walls makes it difficult to be used between rooms.

### 2.10 Comparison of different positioning techniques
The infrastructure, accuracy, advantages, and disadvantages of the previously mentioned positioning techniques are compared (see Table 1). The GPS technique is supported by most mobile devices, but to support high accuracy positioning it requires LoS, Wi-Fi positioning and INS can provide medium accuracy positioning and are more suitable for indoor environments. However, the Wi-Fi solution requires a high-cost infrastructure and has limited coverage, while INS suffers from drift errors[43]. Then there is magnetic positioning which provides very good positioning accuracy and does not require any infrastructure, but one downside of this method is that the magnetic anomalies must be measured and mapped ahead of time before they can provide useful positional data [44].
Table 1. Comparisons of different positioning techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Accuracy</th>
<th>Advantage/Disadvantage</th>
<th>Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic</td>
<td>Very high (0.1-2 m)</td>
<td>No infrastructure/Requires mapping before positioning</td>
<td>Software/Cloud</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>Medium (10-100 m)</td>
<td>Good accuracy for indoor environments and no need for LoS/High cost for infrastructure and limited coverage</td>
<td>Hardware/Software</td>
</tr>
<tr>
<td>INS</td>
<td>Medium (accumulative error)</td>
<td>Cheap/Bias and drifting</td>
<td>Independent</td>
</tr>
<tr>
<td>GPS</td>
<td>High (10 m)</td>
<td>Good accuracy/Line of Sight (LoS) is needed</td>
<td>No requirement for infrastructure</td>
</tr>
</tbody>
</table>

2.11 3D Graphics

One main goal of the positioning system is to provide the clear and detailed representation of location information. Examining the current positioning and navigation fields, vision-based methods are widely implemented and dominate the various applications of the positioning system. The vision system is an important channel for human to access and process the external information. Therefore, besides the discussion on the development of positioning technology, there is also an increasing amount of researches focusing on the visual representation as another noticeable part of the practical positioning systems.

To build the mutual connection between reality and 3D virtuality, 3D models are constructed from the real objects by representing those physical bodies through the set of points in three-dimensional space and connecting them by various geometric entities[45]. Under the background of automated computing in modern technology, the process of 3D reconstruction is widely investigated in recent researches due to its large potentiality in different fields to obtain the computer graphic in three dimension.
Without the requirement of artistic specialty from human, the process of 3D reconstruction is based on the technology of computer vision. Computer vision is a field focusing on how a computer can extract and understand useful information from images and videos[46]. Thus 3D reconstruction which originates from this field refers to the methodology of obtaining the data from images and videos then creating the corresponding 3D models based on the data through vision computing.

This 3D reconstruction technique can be categorized depending on the methodologies. The active methods rely on the actual objects using approaches like rangefinders and other types of active sensing techniques to acquire the depth map. The models are built with a numerical approximation method[47]. While the passive methods are often designed without interference with the reconstructed object in real life but involving the sensors, cameras or other detecting method to acquire the images of the object under ambient or artificial lighting, and to compute the radiance reflected or emitted by the surface of the object inferring the 3D structure of the object[42][43]. The active methods can achieve the relatively higher accuracy and minimize the external effects like scattering or blurring during the data detecting. On the other hand, this kind of methods normally requires the sensing techniques with very high precision, which makes it hard to be generalized. Passive methods are more widely used in application due to the adaptability and flexibility.

The first step in 3D reconstruction is the image acquisition. Among the researches on passive methods, the camera is commonly used in this stage to take the images in many circumstances. To simulate the viewpoints in monocular cues, plenty of experiments on using a single camera or stereo cameras for creating the stereo vision has been taken. The 2D images are the sources for image-based modeling. For different reconstruction methods, different amounts and qualities of images are required. During the reconstruction process, a common problem affects the quality of the result is the unstable reconstruction errors due to the inconsistency of real size and physical motion brings up the problem of calibration which is another important consideration in 3D reconstruction.

Camera calibration is normally the first step in the computing process of 3D reconstruction. It refers to the process of mapping the correspondences between two-dimensional image points and three-dimensional space coordinates. In the traditional way of 3D reconstruction, the system requires the information including 3D location and pose of the cameras or the location of ground control points to facilitate the real size reconstruction[50].

As the growing demand for reconstruction techniques in a wide range of applications, the camera calibration starts to involve the higher level of automation to cope with the use of hand-held camera. A technique called Structure From Motion (SFM) is widely used for self-calibration approaches in 3D reconstruction. SFM solutions have the ability to solve the camera pose and scene geometry simultaneously and
automatically by using a highly redundant bundle adjustment based on matching features in multiple overlapping and offsetting images[50].

2.12 Android platform

The application is developed by the Android programming language and installed on an Android smartphone for testing. Android is an open source mobile operating system which is developed by Google[51]. It is mainly designed for smartphones and tablet computers or other touchscreen mobile devices. It provides different management modules, device drivers, class libraries and frameworks. The widespread acceptance and usage of Android mobile devices are shown by the number of active Android devices, which today is over 1.5 million. Besides mobile applications, the Android platform offers an open-source development platform, a huge amount of built-in services, automatic management of the application, and a component-based architecture. Android applications are developed in Java language using the Android Software Development Kit (SDK).

The Android platform consists of five layers[52][53]:

1. **Application**: This layer is responsible for the user interaction with the device. It is the top layer in the Android platform and contains all the applications on the device, built-in applications such as camera and contacts and applications installed by the user. The application layer is written in Java language.

2. **Application framework**: This layer is also written in Java and implements the standard structure of an Android Application. It contains functions like managing, activity manager, resource manager and so on.

3. **Native Libraries**: This layer is responsible for providing support for the core features. The available libraries are written in C/C++, they are called through a Java interface. The various libraries can be openGL, media framework, webkits and so on.

4. **Android runtime**: This layer is comprised of the core libraries that provide most of the functionalities in the Java core libraries and the Dalvik Virtual Machine which works as a translator between the operating system and the application.

5. **Linux kernel**: This layer is the bottom-most layer in the Android platform architecture, it never interacts with the user. Instead, it is used at the back end for the management of devices, provides support for memory management, network stack, process management and so on.
2.13 Related work

As the increasing demand for indoor positioning services, utilizing the magnetic field information inside buildings for localization is an aspect gathering more and more attention. There are analyses and researches that have been done within these fields, some work has been done for indoor robot localization and some for the localization of mobile phones [46][47] using magnetic fields.

In [56], Chung presented an indoor localization method that used the magnetic field disturbance of the Earth. The study investigates the characteristics of magnetic fingerprints, the performance of the positioning system using the fingerprints and its implementation in a pedestrian navigation system. In this system, magnetic fingerprints are collected by a mobile device while navigating and sent through HyperText Transfer Protocol (HTTP) to a server. In the server, these received fingerprints are then compared with the map fingerprints in the server and then returns the estimated position of the device/object. Even though the system has the capability of covering a wide area, it still suffers from errors and increasing cost as the coverage area increases [57].
Gozick (2011)[38] and S.-E Kim (2012)[58] proposed a work where internal sensors in a mobile device were used to collect and analyze the magnetic field. Around the same period, two other group of researchers, Wang et al.[59] and Constandache et al.[60], also published their discussion about utilizing built-in sensors of the common smartphone to generate the location information and to map the geographic patterns. This kind of works opened up the possibility of using modern mobile devices for positioning purposes without specialized sensors.

In the recent work of Cj Davies[61], a platform for parallel reality was developed. This platform uses IndoorAtlas for indoor positioning technology and the 3D game engine to combine the modern virtual reality hardware of the Oculus Rift.

As for the 3D reconstruction technology, various attempts are also taken due to the increasing demand for high-quality automotive modeling. The researchers show how the amount and property of images will affect the construction through the experiments. An experiment on a two-image reconstruction was taken by Zhang et al.[62] for exploring the use of space intersection algorithm and color differences for finding the geometrical structure of complex objects. As a result, the boundaries of objects can be sufficiently extracted from 2D images. To further develop the detecting algorithm dealing with the complex geometry structure, Han and Burks[63] had sequential images as the inputs for the research. The experiment matched the correspondences between the multiple images for reconstruction. As mentioned in the previous section, the problem of calibration largely effects on the output quality, and it is emphasized in many works. The SFM method of self-calibration is proposed to deal with the uncalibrated images by Pollefeys et al.[64] Based on tracking or matching features the relations between multiple views are computed. From this method, both the structure of the scene and the motion of the camera are retrieved. The ambiguity on the reconstruction is restricted from projective to metric through self-calibration.

### 3. Scientific Methods and Development Models

The scientific methodologies in the thesis are as the systematic process denoting how the goal of both research and practical product are achieved. In the following sections, the choice of scientific methods showing steps of data collection and analysis which are used in this thesis are presented together with the consideration of quality assurance for the research, which concerns establishing different views of the 3D visualization technology in constructing the specific positioning system.

#### 3.1 Data Collection

Data collection refers to the process of collecting data for a research, during this process, different data collection methods can be used.
The system consists of a back-end and a front-end. The back-end part involves obtaining the position information of a mobile device as xy coordinates and storing it in a database through an application. The front-end is the 3D model of the environment. Experimental research methods together with the deductive research approach are selected to measure the accuracy of the positioning system and to observe how the 3D model changes according to the real-time coordinates provided by the back-end positioning system. The data was collected through case study and experiments.

When evaluating the system, accuracy and reliability are of particular interest. The evaluation is done using an experimental research strategy. Hence the nature of the tests is quantitative. This requires testing of the positioning system, the accuracy, and reliability of the positioning are of particular interest when evaluating the system. The experimental research strategy is in the same category as the experimental research method. This method concerns control over all factors that may affect the results of an experiment. By using an experimental research strategy, the research is carried out under the control over all factors that may affect the outcome of an experiment in order to verify or falsify the outcomes of system development and figure out the potential cause-and-effect relationships between variables[12][13].

When testing the accuracy of the positioning system, complete control over the independent variables (number of coordinates transferred to the 3D model and testing area) is obtained. The experiments on the prototype are used to collect data of the positioning function in certain areas for analyzing the accuracy of the system. The data from the experiments were analyzed using statistics. The amount of collected raw data is often enormous, and the analysis is carried out with statistics. The method is used in experiments with large datasets.

3.1.1 Empirical Research Methods
In addition to the experimental methods, empirical research methods are used in the evaluation of the system[65]. They are used in order to test predictions of how the system works in a real-life situation. Observations were used as the data collection method for the empirical research method. Observation methods are useful for researchers in many different ways. They provide researchers with ways to check for nonverbal expression of feelings, determine how a system works in a real-life situation and how the users communicate or interact with each other[65].

3.1.2 Case study
The case study is an empirical study strategy that investigates the certain phenomenon in a real situation.[66] The cases are selected around the related technologies with the same purpose but different working principles, which have been applied to different problems and different circumstances. By analyzing the cases in
depth, the data for potential techniques are collected and presented in a way showing the strength and limitation in certain occasions for further evaluation and research. During this data collection process, a relatively large amount of texts and documents about priori experience are included. Thus the method for interpreting the useful information is also needed.

From the practical perspective, the data is also collected from the actual implementation. As a research with practical concern, the research is performed by actions for real problem-solving orientation. After the implementation of the visualized positioning system in practice, some forms of inputs are applied to the experimental unit and the responses shown in the data set of performance outcomes can be observed by experimental testing.

3.1.3 Use case study

In a qualitative research, data collection for validating the performance of the product should also be emphasized in order to ensure the quality of the product. The interview is one of the common methods for collecting the feedback from potential users to explore their views and experience[67]. A research interview can be carried in various forms. Structured interviews are often designed beforehand with a list of predetermined questions. Semi-structured interviews are designed to be more general. A semi-structured interview consists of several key questions which allow the deeper exploration in conversation afterward. Meanwhile, there is another type of interviews called unstructured interviews. As an opposite type of structured interviews, unstructured ones tend to start with some open questions and progress the conversation without pre-organized.

In this research, the focus group can be varied. The group dynamics caused by different backgrounds and perspectives can lead to various reflection on the product validation and user experience. For further data analysis on the feedback based upon group dynamics, the forms and structures of interviews for different focus groups are specially designed.

3.2 Data Analysis

To systematically analyze the implemented system around the problem proposed at the beginning of the research, the collected data is inspected and evaluated together with the data from priori researches and experiences. The analysis includes searching and arranging collected data, synthesizing and collecting what is important for the research. In order to create explanations and draw conclusions, the researcher must overview and organize all the collected data. Grounded theory is used for collecting and analyzing data and statistics is applied to test the hypotheses and making the research project valid.
Due to the scientific nature of the research, the analysis of the literature sources focuses on developing a theory that is based on data, by systematically collecting and analyzing data. At the investigation stage, the aim of data analysis is to identify the common pattern of priori researches and evaluate the experiments critically for concluding the suitable techniques to use for practical system construction, and also to analyze data from the results. When the primary implementation is finished, the outcome data is expected for further evaluation of the performance and possibility of the designed system. The data analysis in this stage is a process of drawing inductive inferences from the experimental data.

3.3 Validation and Verification

In a research, it is necessary to evaluate its result to confirm its validity and relevance to the research. The validity and reliability of the research are usually considered. The validation and verification of the research material are often ensured by quality assurance. For assuring the quality of the research of indoor positioning system and its interaction with the 3D model, validity, replicability, dependability, confirmability, transferability, and ethics must be discussed. The purpose of validity is to make sure that the test instruments are measuring what is expected to be measured. Reliability refers to the stability of the measurements and the consistency of the testing results. Replicability is the possibility, by another researcher to achieve the same results when repeating this research. Ethics, covers protection of participants, maintenance of privacy and is the moral principles in planning, conducting and reporting the results of research studies.

The thesis is meant to have a remarkable research value and should keep a high standard in academic level. Therefore, it is very important that the research process, the sources that are the basis for this work and the implementation process are highly reliable. The sources that are used should be academic and the information in these sources should be double-checked with other academic sources and tests concerning the positioning accuracy will be carried out for ensuring validity. The implementation process should be well documented and the procedures well-described for ensuring replicability.

To verify the functionality, the unit test and integration test are proceeded after the implementation of the experimental system. The usability is verified during the case study taken in real sample environment by comparing the real situation and the outcome of the system display.

Unit testing is a process of testing the individual components in a system[68]. Instead of being interested in the performance of the whole system, this type of testing focuses on the smallest testable components to check if every piece of the system works properly. The validation tool for unit testing is own debug functionality of
coding environment. By setting endpoints at the lines of code that need to debug, the program runs into the endpoints and starts a debugging step into the function. The step shows the variables and process number of the current step in function. By checking the returned variables and verifying every unit, it can be ensured that they are implemented correctly.

Integration testing is the process of integrating all units or modules and testing the system as a whole[69]. According to the way of integrating the unit step by step, the integration testing can be done in three ways: Big Bang, Top Down, and Bottom Up approach. The Big Bang approach is about combining all the modules once and testing the functionality and continuity of the system, therefore the method requires that all parts of the system are completed and ready for testing. Top Down and Bottom Up approach, as names suggested, follow the orders of module levels. In the Top Down approach, testing takes place from top to bottom. The top of the system refers to the higher level module. While the Bottom Up testing starts from the basis first.

3.4 Software development method

As a software engineering project, the scientific software development method is applied for managing a set of interrelated tasks in order to meet the goals and objectives of the thesis. Since the project is designed for software development, the work including computer programming, documenting, testing and bug fixing are taken into account in the planning and work management. Because the scale of the project is relatively large and the research topic is wide, the Essence Kernel which is a simple state-driven model of software engineering is used as the thinking framework during the thesis work[70]. The progress has been monitored, and the principal of activities is defined through the key concepts of the kernel: Requirements, Software System, Team, Work, Way of Working, Opportunity, and Stakeholders.

Waterfall development is the process model used for this thesis project. As a software development approach, it tends to follow a relatively linear sequential structure to organize the work[71]. As a project with clear objectives and requirements, this method suits for the milestones-focus fact with limited time. It suits the self-organized property of this thesis, and its clear working structure is beneficial at the condition where the participants of the thesis are inexperienced on the time management and work estimation for the large project. The waterfall model divides the work into distinct phases following the sequential logic.
**Figure 4. Waterfall model of software development**

**Requirement:** This is the initial stage of the waterfall model. In this stage, the potential requirement from the stakeholder is collected and the specification of the outcome of this thesis is analyzed in order to achieve the objectives. This is an essential part of this thesis project since the nature of the waterfall model leads the participants to complete the works before stepping to the next stage. It means there is no iterative process of this thesis for changing the requirement.

**Analysis:** With the understanding of the requirement, the potential background knowledge required for prototype implementation is analyzed and researched in this stage.

**Design:** The design phase is still a theoretical phase in this project but includes all the technical consideration of the project into the design. The actual technologies used for implementing the experimental system is decided in this stage. During the designing, a flowchart describing how the system should be structured and technically implemented is made.

**Coding:** This is the practical stage for the project in which the actual implementation should be done. This includes setting up the application used for experiments, writing the source code and integrate the whole prototype.

**Testing:** After the experimental system is built, the purpose of this phase is to check if the system function properly as expected and to discover if there is any issue affecting the outcome.
Operation: This is the final stage of this step by step project. At this stage, the experimental system is deployed to a real-life environment for monitoring the performance for further evaluation.

4. System investigation and implementation

In this 3D visualized indoor positioning system, IndoorAtlas, Android software platform, Microsoft SQL Server database, Unity 3D and Visual SFM were selected. The smartphone application IndoorAtlas is used to collect magnetic fingerprints for positioning purposes. The data is collected and imported to a MySQL database, where it will be fetched and used for three-dimensional visualization purposes in Unity3D. The client-side application is coded in Java language running on an Android platform and a MySQL database is used to support the server side applications. The indoor magnetic field is used to create a reference map for localization, but for estimating the initial position, Wi-Fi will be used.

4.1. Requirement analysis

In the situations where the vision is very limited, it is important to have an overview over the surrounding environment and objects. There is a broad range of different positioning techniques and technologies that can be used for this purpose. But due to limitations, some of these techniques could not be used for this project where the goal is to construct a practical simulation of an indoor positioning system which presents the location information through 3D visualization. A system where positioning of objects are presented with a 3D display provides a much more clear view of the surroundings and the objects in it.

Based on the requirements needed to be taken into consideration while developing the prototype. During the research and evaluation, an indoor positioning system using RFID tags is accurate but the construction is costly. The usage of a camera is also an approach however it could lead to an intrusion of privacy. It would violate the privacy of its inhabitant (in a living environment) while it would not be capable of capturing a room in detail if the room is full of smoke. Another concern is the installation and maintenance of devices that require electrical power, systems that do not require any wired infrastructure are easier to install, but the batteries still need to be maintained and replaced at all the nodes, which is time-consuming. If the electricity goes down during an emergency situation, none of the receivers or transmitters will work if they depend on electricity. So it was concluded that a system that does not require any kind of infrastructure would be the optimal choice.

For this prototype, an approach using the built-in sensors in a smartphone is used. As mentioned in the theoretical background, smartphones have become more advanced
thanks to its many components, they have also become smarter in the sense of awareness. Most of the mobiles today have awareness in shape of integrated sensors providing the opportunity of reading its state of position and motion and was therefore a sensible choice for our project. In order for the system to be as flexible as possible, without any dependency on external hardware a positioning system that uses magnetic fields is preferable, where a smartphone and its built-in sensors and a map of the building, no other external hardware or infrastructure is needed.

There are some requirements that the product needs to fulfill besides being able to track objects indoors, positioning data needs to be collected through a smartphone application and transferred to the database simultaneously where the data is fetched into Unity 3D, the positioning coordinates need to be accurate and match the corresponding coordinates in Unity 3D.

As mentioned in the theoretical background, most smartphones contain multiple sensors including a magnetometer, gyroscope, and accelerometer. For this project, the initial position is obtained by other methods such Wi-Fi and Bluetooth (if available), the smartphone sensors can then be used to track the position of an object inside a building or a room. The magnetic sensors can then pick up the magnetic field of the Earth to determine the latitude and longitude position of the device, but two dimensional and a lot more accurate.

The requirement of the system also assumes the users do not have the hardware assets and profession in 3D modeling and rendering. Thus the software-based 3D reconstruction solution is considered in this prototype.

4.2 Used technologies and environment

For the work in this research, an evaluation phase of different indoor positioning systems is taken in order to determine a suitable technology. Due to some limitations, considering the requirements, assets available for the project as well as environmental aspects, an indoor positioning system independent from any kind of external hardware was preferable. Thus, a magnetic field based approach was selected for localization by the magnetometer embedded in a smartphone and to use a client-side application based on Android for collecting the information in the calibration phase and obtaining the position in the positioning phase. There are numerous systems mentioned in related work that use the magnetic field for indoor positioning purposes. However, not all of them were applicable for this project due to the actual goal of the thesis, where a frequent update of the positioning coordinates was needed. While all of the works used the magnetic field for indoor positioning purposes, not all of them were suitable to use in combination with a 3D display since some of them suffered from errors and were not completely reliable. But in the work of CJ Davies, the location of a mobile device was retrieved using an application called IndoorAtlas,
which uses the built-in sensors in the mobile phone in order to sense the magnetic field inside buildings to get the positioning coordinates of the device. This was also used in our work where the application was modified so that only the latitude and longitude coordinates were sent to the application and frequently updated while moving the device.

IndoorAtlas location technology uses a sensor fusion algorithm that combines every source of position-related data with a basis in magnetic field sensing for accurate positioning. Since the main goal of the project is to create a 3D picture in order to pick up signals to create a 3D model of an environment, IndoorAtlas SDK was modified in order to get the real-time coordinates of a mobile device that would be imported into Unity in order to visualize the equivalent 3D model coordinates in a environment.

4.2.1 Positioning applications

Positioning systems are a core technology in mobile computing to provide the foundation of context-aware services, the market is already established and there are a number of companies that have been developing different solutions during the years. Many different IPS technologies were examined throughout the project in order to find the most suitable, considering the requirements, assets available for the project and also environmental aspects. While some of the technologies mentioned in related work require specific types of devices installed in the environment, an indoor magnetic field approach uses the magnetic field of the Earth that interacts with steel and other materials found in structures of buildings. The utilization of built-in magnetometer as well as other sensing technologies within the smartphone will enable the software to use the magnetic field inside the building as a map to accurately give the position of a device indoors. This was the approach used in this project due to its simplicity, low cost, decent accuracy and the fact that no infrastructure is needed. The technology used for this purpose was the technology behind the IndoorAtlas application, which uses a sensor fusion algorithm combining every source of position-related data with a basis in magnetic field fingerprinting for accurate positioning. It is a hybrid indoor positioning platform that can fuse all available information sources and find the position of a mobile device by using several different positioning technologies[72]. By using the IndoorAtlas Software Development Kit (SDK), positioning coordinates (latitude and longitude) for the Android device could be received on the application.

The IndoorAtlas technology is based on reporting positions in routes that previously have been mapped in the offline phase. The idea behind this application is that buildings have predictable magnetic fields caused by structural steel, wiring, machinery and so on. and by recording the variations, it is possible to characterize an entire building and use that data to position the device within that building. IndoorAtlas does not depend on any deployed infrastructure such as beacons or any kind of tags. Thus, it was suitable for the 3D visualized indoor positioning system, the
only required hardware is a smartphone device that has a built-in gyroscope, accelerometer, and sensitive magnetometer.

This solution does not require any external hardware as it relies on magnetic fields for navigation and positioning, but it uses Wi-Fi and Bluetooth for rough positioning, Wi-Fi- RSSI fingerprints are used to provide an initial position and also to improve accuracy.

4.2.2 Software Environment

Software environment in this system plays the essential role in the performance of 3D visualization. The 3D visualization system is responsible for processing the data from the relational database and computing the 3D representation accordingly. Based on the requirements, two factors are taken into account during the selection of the suitable platform. First, the software environment should have the ability to build a real-time connection with the external database. The scripting is expected to be flexible and support the mutual communication with various platforms. Secondly, the environment should provide the capability of 3D visual representation rendering concerning the performance of the data display function in 3D. In terms of 3D displaying function, the 3D software systems supporting virtuality simulation and analysis such as WRLD3D and Second Life are examined. This type of simulation platform has the distinct positioning system integrated and allows the users to freely add and modify the 3D visual contents in the simulated environment in real time. However, each platform relies on a single asset storage system, which potentially leads to the potential lag when the demands for data and asset are sent. The assets are uniformly generated and rendered which consumes the graphics hardware and lower the performance of the general system. Meanwhile the lack of mesh results in the less realistic graphics and less immersive user visual experience. Based on the comparison, the game engine is utilized as the platform for 3D representation. The features of dynamically load assets in the environment and generating the display of objects when it is visible to users procedurally increase the efficiency of the real-time simulation. The demand for implementing cross-platform games makes many game engines flexible and supportive to various platforms and devices. The mesh-based 3D graphics secure the quality of data representation.

Unity3D as a game engine with an intuitive workflow and custom rendering engine is used in this system[73]. The software platform has the advantages of thorough API provision and flexible integration. Due to the goal of cross-platform game development, the graphic engine is highly optimized to render the visual representation.

4.2.3 Database

Because the procedures of processing data and generating the display are implemented by the computer, the position data obtained by the mobile application
in this research requires a method for transferring data from mobile applications to the computer-based software platforms. In this context, the position information is collected from reality as a data set for further organizing and computing. The external database is a capable solution to hold the data and to allow the data capturing, analyzing and being fetched through the database management system. The common functions of this type of computer software applications provide the capability of the system to interact with various end users. Among the different the functionalities of the database management system, the function of retrieval is the main reason for this solution to be selected. The common database can provide the captured data in a form that can be usable and compatible for direct usage or further processing by other applications.

For various database management systems, the Structured Query Language (SQL) is one of the most widely used database languages for managing and processing data. In this designed system, the data is organized and stored in a structure following the chronological order in the database, which requires to be easily fetchable by the software application for updating the new inputs. The SQL is very suitable for the need of quick reaching and accessing many structured records by simple commands.

In order to build the connection between IndoorAtlas and Unity engines for achieving the data transfer, the external SQL database is applied for storing the position data obtained from IndoorAtlas installed in an Android smartphone and sending towards the Unity platform on the computer. MySQL is used in this system for the experiments. MySQL is an open source database management system. Due to the scalability and real-time analytics ability, MySQL is designed and optimal for data storage in web-based server or application using PHP (Hypertext Preprocessor)[74]. The mobile client using IndoorAtlas is able to communicate with the remote MySQL by building HTTP post requests to send data to the database server over the network by using Data Transfer Objects and hibernate ORM to in order to map to the database. PHP plays the role of contacting applications and servers and is used in our project for fetching data from the database.

MySQL stores the data in tables. This target data can be reached easily for real-time analytics. MySQL in this system is not only used for storing the most up-to-date position data and providing to either mobile application and Unity platform whenever the fetching query is received by the database server but also includes administration functions of the database. phpMyAdmin is used as the administration tool for the MySQL allowing the remote logging and data sharing. It provides a front-end interface for database and has the advantages for not restricting the location information storage by the local storage of mobile devices. It is also a tool for monitoring the performance of database and data transfer.
### 4.2.4 3D Reconstruction

In the case of creating a new object into the simulated 3D environment, the preliminary automotive mechanism is considered in this experiment using 3D reconstruction for modeling. As stated in the theoretical background, 3D reconstruction can involve the advanced commodity hardware sensors for modeling the complex 3D surface in real life. On the other hand, there is also the reconstruction technology supporting the situation where the hand-held cameras and specific software are simply used. By using the tool with a dense reconstruction system, the software is able to estimate the general surface model according to the obtained camera pose. Among the various dense reconstruction systems, Structure from Motion (SfM) algorithm is selected due to the flexible requirement on the quality of the camera. The models are generated through a set of images taken from overlapping perspectives, as shown in Figure 5.

![Image](image_url)

Figure 5. Working principle of the SfM algorithm based on dense reconstruction[75].

(a) The tools using SfM algorithm turn the image set into a 3D point cloud providing the initial scenes by matching the data from these overlapping images. (b) A base surface is created through fitting to the point sets. (c) The algorithm selects a reference position $P_{ref}$ on the base surface and is able to generate the surfaces around this reference position due to the fact that the images are taken with different perspectives leading to the surfaces overlapping. (d) Taking the surfaces, dense reconstruction is performed to create the basic model by measuring the frames and estimate the depth. (e) In the end, a detailed surface model is formed by integrating all constructed surfaces during which all redundant vertices are cleaned.

In this project, modeling the general 3D scenes of the indoor environment is done in Unity engine since the engine provides the powerful enough modeling function. For the detailed objects in the scenes, the Visual SfM is used for reconstructing the 3D models from photos. The Visual SfM is an open-source 3D reconstruction application made by Changchang Wu[76] using the SfM algorithm. By utilizing the multicore parallelism for feature detection, feature matching, and bundle adjustment, the application has the advantage on efficiency and time cost. The application integrates the execution of the PMVS/CMVS toolchain from Yasutaka Furukawa, which supports the real-time analysis of dense reconstruction. In this system implementation, Visual SfM is used as the tool for 3D reconstructing the new objects which are added to the simulated 3D environment as a test of automotive modeling function for users in the future.
**4.2.5 IndoorAtlas**

In order to use IndoorAtlas, registration is required. Registration provides the user to manage floor plans, maps, API keys, secret keys, and applications. The API key and secret key are used in the application development process for accessing the IndoorAtlas API (Application Programming Interface). The next step is to specify the location (building or venue) where the indoor positioning is deployed. As an indoor environment, floor plans can be included in this step as the materials for mapping and storing context information[77]. The location is created on the web application of IndoorAtlas by specifying the name and address of the location, next a floor plan of the building (Electrum) was uploaded and aligned accurately in the map tool. The floor plan of the building was then used for defining the indoor coordinate frames on which the mapping (fingerprinting) process is done. During the mapping process, signal data from the location is gathered by using the MapCreator 2 application. It is also important to map the whole building or environment to get accurate coordinates. The first step in the mapping process is to calibrate the sensors of the mobile device using the same application. The calibration involves first placing the device on a flat, stable surface in order to calibrate the gyroscope, and then rotating it around its different axes to calibrate the magnetometer. After the calibration is done, waypoints were placed on the floorplan using the “add waypoint” function of the MapCreator 2 to plan the walking route for collecting the data. Magnetic field fingerprints are collected and stored as reference points with their corresponding location information. For this to happen accurately, the mobile device was used at every selected reference point for a few seconds. After walking through and checking in on each waypoint, the path is saved. The recorded paths are used to generate the signal maps that enable indoor positioning. After mapping the location, the map is generated and can be used for online positioning, the process of online positioning and the calibration phase are explained in the theoretic background. The IndoorAtlas SDK was used in order to get the exact coordinates of the mobile device in the target location.
4.3 System Implementation

After mapping the target area by going through the steps described in Section 4.2.6, the SDK of the IndoorAtlas is modified for being able to present the real-time position coordinates for latitude and longitude as an output. An application is developed to show the data on the display. No further calibration is needed for getting the real-time coordinates of the mapped area. Also, a start/stop button was added to the application in order to control the number of coordinates sent to the database. The Android phone with the modified application installed establishes the connection with a remote MySQL database server by using spring and hibernate with Java Persistence API (JPA). JSON is used to send data between the different programming languages. Data Transfer Object (DTO) is used to encapsulate data. In this case, the coordinates for latitude and longitude in a value object that can be transferred over the network.

The network requests are managed by Volley, which uses a RequestQueue to pass it request objects. The Volley library makes networking much easier by offering the automation of the network operations. When handling requests, the function layer needs to access and read information from the database. To make this transfer into the Java-based function layer, Hibernate has been used. Hibernate is used for mapping to the database. It provides a framework for mapping an object-oriented domain model to a relational database. What makes this suitable to use is the fact that

![Figure 6. Workflow of the system](image)
the tables in the database have corresponding Java-objects so when accessing and retrieving data from the database the response will be a list of those objects.

When the request has been processed by using the access to the database, the response is ready to be sent. Android makes a call to a Representational state transfer (REST) API, the API stores the data in the database by using JSON post requests, this request does an HTTP post of a serialization of the object, gets the response and parses the response into a JavaScript value, this response will contain all the necessary information. The objects will contain coordinate values of the current position as the parameters to the database. The coordinates stored in the database will get updated according to the positioning coordinates of the mobile device.

The MySQL database stores the submitted position data in a table form where column named "longitude" and column named "latitude" hold the coordinate values respectively for further parsing. The data is organized by an integer as the index recording the chronological order of receiving data. In the Unity3D engine, a scene of immovable elements within the indoor environment such as walls and floor is modeled based on the corresponding scaled-down floor plan. To model the monitored object, 50 to 500 images from various overlapping perspectives are taken and imported into the VisualSfM software program. The dense reconstruction is completed by this program and it outputs a dense point cloud. The process of creating mesh is done by the surface reconstruction function of MeshLab. It also allows the further sculpting and cleanup in order to achieve a better and more realistic visual experience. The whole procedure results in a 3D model in FBX format which can be imported into the Unity3D as a game object.

The visualization mechanism in Unity3D is accomplished by two main scripts written in C#. The scripts are attached to the game object simulating the monitored object in real life. The purpose of the script is to ask for the updated position data from MySQL database and to generate the movement of the object towards the target coordinate. In the script "InputLoader.cs", the WWW module is used in sending a GET request to the remote MySQL database and retrieving contents of the PHP page for coordinate parameters.

To translate the real world position data submitted by IndoorAtlas to the virtual world position in the simulated environment within Unity3D, an anchor point is set for coordinate transformation and calculation. In this implementation, the anchor point is set as the initial position where the IndoorAtlas starts to report the signals. Once the mobile client sends the position data for the first time, the longitude and latitude coordinate of the real world anchor point is known and fixed by the system. The coordinate is represented as (anchorAtlasX, anchorAtlasZ). Meanwhile, a sphere object without texture and collider is placed at the initial position by referring the floor plan reference, and its coordinate data in the Unity3D environment is read as (anchorUnityX, anchorUnityZ). Each time when a movement of the monitored object...
happens in the real world, an updated position data is submitted to the database and retrieved by the Unity script. For processing the data, the displacement of the position change is calculated and scaled down according to the scale of the floor plan used for modeling the environment. The procedure of computation is shown in Figure 7.

```csharp
void UpdateNewPosition(float NewInputX, float NewInputZ)
{
    float xDiffReal = NewInputX - anchorAtlasX;
    float yDiffReal = Mathf.Deg2Rad * (6371000 / scale) * Mathf.Cos(Mathf.Deg2Rad * (NewInputY + anchorAtlasY) / 2);
    print("X: ", xDiffRealReal + "/" + yDiffRealVir);
    float zDiffReal = NewInputZ - anchorAtlasZ;
    float zDiffReal = Mathf.Deg2Rad * (6371000 / scale);
    print("Z: ", zDiffReal + "/" + zDiffRealVir);

    if (NewInputX > anchorAtlasX)
    {
        xNewPos = anchorUnityX + Mathf.Abs(xDiffVir);
    }
    else
    {
        xNewPos = anchorUnityX - Mathf.Abs(xDiffVir);
    }

    if (NewInputZ > anchorAtlasZ)
    {
        zNewPos = anchorUnityZ + Mathf.Abs(xDiffVir);
    }
    else
    {
        zNewPos = anchorUnityZ - Mathf.Abs(xDiffVir);
    }
}
```

Figure 7. Calculation from real coordinate to virtual coordinate

This gives the difference between the current position and the new position in the virtual environment within Unity3D. After going through the calculation of difference, the virtual model of the object can move towards the corresponding position by following the displacement in Unity3D coordination system.

5. 3D visualized indoor positioning system

The outcome of system implementation and its usability are assessed separately. The empirical research strategy is applied in the testing phase of the system implementation. A case study is carried out in order to examine the functions of the experimental systems as a whole and the usability in a real situation. The testing result is presented respectively in the following sections:

5.1. System implementation result

As a project aiming for building an experimental system, the result is presented as an assessment of the reliability of the system. The system implementation result mainly focuses on the functions of the built system separated by the mobile application, Unity environment and database connection. In order to examine the reliability of each module in the prototype, the experimental research method described in the previous scientific method section is used for testing of the system implementation.
In order to assess the reliability of the back-end part of the system, an evaluation is needed. The evaluation includes collecting positioning which is sent to the database continuously. The application was used in order to collect coordinates in the mapped area of the Electrum building, the positioning coordinates of the mobile device are retrieved and shown on the application as output. To ensure that the coordinates match the area, they are compared to the set of reference points in that area. In that way, an estimate is given of whether the coordinates are measuring the right position or not. By repeating this process in different rooms and areas of the building, reliability can be ensured.

As for front-end, the output data regarding the positioning information and remote connection is presented at the GUI in Unity inspecting the real-time updating of public variables, as shown in Figure 8. Besides the visualized information which is presented as the change of virtual 3D scene, the data variables are updated and monitored numerically every time when a new set of position data from the remote database is fetched and processed.

![Figure 8. Parameters for movement generator](image)

The tests of each function are taken with the control over all other factors that may affect the result of the tested functionality in order to minimize. In this case, the single object target is controlled for performing the experiments with the multiple various positioning datasets. The visualizing factors like velocity, turning angle and turning speed which only affect the performance of movement display are controlled in the same configuration. Based on this strategy, the integration test for different functions are performed and the result is presented in Table 2.
<table>
<thead>
<tr>
<th>Test Objectives</th>
<th>Steps</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Verify the function of MySQL database table.</td>
<td>1). Connect the Wamp server. 2). Taking five random sample sets containing three values. 3). Open the phpmyAdmin front-end interface by going to '<a href="http://localhost/phpmyadmin">http://localhost/phpmyadmin</a>'. 4). Insert one set into the MySQL table each time in column 'Longitude', 'Latitude', 'Id'. and open the PHP page '<a href="http://localhost/ConnectUnity/LocationInfo">http://localhost/ConnectUnity/LocationInfo</a>' in a new tab.</td>
<td>1). The icon of the Wamp server turns green. 2). The PHP page shows the corresponding inserted values in the form of 'Longitude</td>
</tr>
<tr>
<td>2 Verify the data transportation from the mobile application to the MySQL database.</td>
<td>1). Start the mobile application 2 2). Press on the “Start” button to start searching for positioning coordinates, press on the “Stop” to stop the application from generating more coordinates.</td>
<td>1). The real-life coordinates displayed on the mobile phone are stored in the database.</td>
</tr>
<tr>
<td>3 Verify the connection between MySQL and Unity environment.</td>
<td>1). Connect the Wamp server. 2). Taking five random sample sets containing three values. 3). Open the phpmyAdmin front-end interface by going to '<a href="http://localhost/phpmyadmin">http://localhost/phpmyadmin</a>'. 4). Insert one set into the MySQL table each time in column 'Longitude', 'Latitude', 'Id', and run the Unity program.</td>
<td>1). The icon of Wamp server turns green. 2). The console window in the Unity shows the corresponding inserted values in the form of 'Longitude</td>
</tr>
<tr>
<td>4 Verify the function of value parsing.</td>
<td>1). Taking five random sample sets containing three values. 2). Insert one set into the MySQL table each time in column 'Longitude', 'Latitude', and run the Unity program.</td>
<td>1). In the Unity inspector, the public double variable NewInputLongitude, NewInputLatitude, NewInputHeight show the corresponding inserted values in each column.</td>
</tr>
<tr>
<td>Step</td>
<td>Task</td>
<td>Steps</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
<td>-------</td>
</tr>
</tbody>
</table>
| 5 | Verify the calculation from a real-world position to virtual position. | 1). Insert five random sample sets containing three values. into the MySQL table in column 'Longitude', 'Latitude' and run the Unity program.  
2). Calculate the displacement between every two sets and divide it by the scale.  
3). Run the Unity program. |
| 6 | Verify the capturing of a mouse. | 1). Insert five random sample sets containing three values. into the MySQL table in column 'Longitude', 'Latitude' and run the Unity program.  
2). Press the left key of the mouse.  
3). Press the left key six times. |
| 7 | Verify the movement of the object in the virtual scene. | 1). Insert five random sample sets containing three values. into the MySQL table in column 'Longitude', 'Latitude', 'Height' and run the Unity program.  
2). Press the left key of the mouse for four times |

| 1 | In the Unity inspector, the targetPos is updated and shows the correct result comparing to the calculation of displacement. |
| 2 | In Unity inspector, the targetPos updated.  
2). The object move towards the target position, the myPos is updated to the target position when the movement is finished.  
3). The virtual position looks properly comparing to the real world scene. |

As mentioned in the scientific method chapter, the results of the prototype experiments are verified by the unit testing with own integrated debug functions of the coding environment. In this experimental system, Java and Visual Studio debugging tools are both used. In the example of Figure 9, the fetching data values function takes the coordinate (Longitude, Latitude) as the new inputs. The breakpoint is set after the difference in real coordinate is computed. As it can be seen that the input X values is 17.949678 while the previous reference point is 17.949441, thus the returned value xDiffinReal is 0.0002365. After comparing the returned values with expected results, the function works properly since it returns the correct values. By going through the debugging tool, the result of system implementation in each specific module is verified to be correct.
Figure 9. Visual Studio debug function.

As for the performance, the result is presented regarding different modules in the integrated system. Positioning function is a module which has its large impact on the performance of system implementation. According to the authorized literature offered by IndoorAtlas[78], the accuracy of magnetic field mapping technology used in this system is in a range of 0.1 meters to 2 meters. This is concerned as the accuracy of the position detection function in this system. The uncertainty is also measured by collecting five sample positions from running the system. To minimize the possible systematic error, the location data at one position is collected for six times and the average value is computed. The raw data result presented in Table 3 demonstrates the uncertainty and accuracy of the general system computing.

Table 3. Raw data for the experimental system

<table>
<thead>
<tr>
<th>Trials</th>
<th>Position 1</th>
<th>Position 2</th>
<th>Position 3</th>
<th>Position 4</th>
<th>Position 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual 1</td>
<td>(-0.5, 2.0)</td>
<td>(1.9, -0.1)</td>
<td>(6.2, -2.9)</td>
<td>(9.9, -5.4)</td>
<td>(17.7, -5.2)</td>
</tr>
<tr>
<td>Virtual 2</td>
<td>(-0.4, 2.4)</td>
<td>(2.7, 0.3)</td>
<td>(6.6, -2.7)</td>
<td>(10.3, -5.0)</td>
<td>(17.6, -5.9)</td>
</tr>
<tr>
<td>Virtual 3</td>
<td>(-0.3, 1.8)</td>
<td>(1.8, -0.4)</td>
<td>(6.1, -2.9)</td>
<td>(10.3, -4.8)</td>
<td>(16.6, -5.7)</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>(-0.6, 1.6)</td>
<td>(2.7, -0.1)</td>
<td>(5.2, -3.1)</td>
<td>(9.4, -5.2)</td>
<td>(17.3, -6.1)</td>
</tr>
<tr>
<td></td>
<td>(-0.9, 2.4)</td>
<td>(2.4, 0.1)</td>
<td>(7.0, -2.9)</td>
<td>(8.9, -5.0)</td>
<td>(17.8, -5.7)</td>
</tr>
<tr>
<td></td>
<td>(-0.7, 2.2)</td>
<td>(3.0, -0.4)</td>
<td>(5.9, -2.5)</td>
<td>(10.0, -4.6)</td>
<td>(17.5, -5.2)</td>
</tr>
<tr>
<td>Real</td>
<td>(-0.6, 2.1)</td>
<td>(2.4, -0.1)</td>
<td>(6.2, -2.8)</td>
<td>(9.8, -5.0)</td>
<td>(17.4, -5.6)</td>
</tr>
<tr>
<td>Average</td>
<td>Lat: 0.000008 Lon: 0.000018</td>
<td>Lat: 0.000006 Lon: 0.000012</td>
<td>Lat: 0.000006 Lon: 0.000013</td>
<td>Lat: 0.000008 Lon: 0.000017</td>
<td>Lat: 0.000009 Lon: 0.000016</td>
</tr>
<tr>
<td>Uncertainty of positioning</td>
<td>X: 0.3 Z: 0.5</td>
<td>X: 0.6 Z: 0.3</td>
<td>X: 1.0 Z: 0.3</td>
<td>X: 0.9 Z: 0.4</td>
<td>X: 0.8 Z: 0.5</td>
</tr>
</tbody>
</table>

As demonstrated by the sample computations, the largest uncertainty of the latitude detection is ±0.000009 degree while the largest uncertainty of the longitude is about ±0.000018 degree. Meanwhile, the calculation based on the geographical position for obtaining the virtual coordinate in the simulated environment has the potential uncertainty of ±1 pixel in Unity coordination.
5.2. Case study result

After the testing and validation of the system implementation, a case study is conducted in the real world situation. The case study demonstrates the usability and capability of the prototype built in this project. Data was collected through scientific studies of reality, our predictions were tested by suitable experiments and observations.

As introduced features of indoor positioning technology based on magnetic field, the usability and accuracy of the experimental system largely depend on the building materials. The experiment is carried out on the first floor of KTH Kista campus. Based on the fact that the Electrum is a modern building and the material consist of structural steel, the prediction was that the experiments would have an accurate outcome due to the disturbance of the magnetic field when it comes to the position information. By conducting an empirical research, knowledge was gained by getting proofs based on evidence from the experiments and observations. The data is analyzed from the observable evidences that are collected.

The basis environment of the Electrum building is modeled according to the floor plan, as shown in Figure 10. By referring to the floor plan of the building, the unmovable part in this building such as walls and floors can be mapped into Unity3D with a certain scale.

![Figure 10. A static 3D environment built on the floor plan. KTH, Electrum building.](image)

In this case study, the mobile phone with application installed simulates a specific object in the environment shown in Figure 10. and its position is monitored. During the experiment in the case study, the initial position of the object is set at a corridor at first floor where it gives the longitude and latitude (17.949441, 59.404968) with height of one meter. The corresponding point on the floor plan located on (-13, 0.5, -15.2) as Unity coordination system. These two points are regarded as the initial
anchor points for calculation the position change from the real world to Unity environment.

Figure 11. Anchor point in Unity3D

To test the functionality of the system allowing users to add new 3D objects into the environment without specific 3D modeling skill, a watermelon is selected as an experimental object to be added into the simulated environment. Figure 12 presents the outcome of 3D model reconstruction of the experimental object. The process takes 185 images from different overlapping perspectives. As it can be observed, the point cloud is computed in the right perspective and the surface model is completely constructed without too many redundant vertices.
Figure 12. 3D reconstruction of the sample object

The test of mapping the building with IndoorAtlas is done and the result is shown below:

Figure 13. Test of IndoorAtlas mapping function in KTH building.
By observing the position mapped using the IndoorAtlas application, it can be seen that the distance between every two red points is around two meters. This represents the actual accuracy of the positioning, in this case, the building structure and the material of this indoor environment may have an impact on the accuracy. In the same time, the function of reporting the position of mobile devices is tested and the ability to present the real-time positioning coordinates is shown in Figure 14. The update of the result is accurate since the multiple digit decimals make it possible to capture the tiny movement on position. The mobile application shows the current positioning coordinates and a star/stop button is implemented in order to control the number of collected coordinates. The corresponding update of coordinate values also happens in the remote database.

Figure 14. Real-time coordinate on mobile application
In general, the direct result of the experimental system in this case study can be observed by comparing the movement in real time and the update status of the 3D virtual environment. The comparison is presented in Figure 15.

Every time the mobile client moves towards a new position, as the situation in Figure 15.1(a) which shows a newly updated position of the mobile client. By observing the corresponding 3D environment on computer shown in 15.1(b), the object moves accordingly to the new position in Unity. Through the comparison of the surrounding objects and positions from (a) and (b), the movements are identical and considered being computed correctly. However, there are also some cases when the position of the object in Unity does not follow the exactly precise position where the real object moves to, like in Figure 15.2. In the figure 15.2(a), a new position is updated while 15.2(b) shows that the object moves accordingly based on the data it processed but it ends up with a position which is not identical to the real world location. It can be observed that the object even sticks into the wall in figure 15.2(b) due to the imprecise
position. Through the multiple tests in real situations, the deviation of the updated positions is within two meters.

5.2.1 Use Case Result

In order to evaluate the system and analyze whether it meets the customer expectations and requirements, use case testing was conducted. During this procedure, the actors were given some information about the system and what it is supposed to do before trying it step by step. After the use case testing, the actors were interviewed. They were asked about their thoughts regarding the different parts of the system, how practical it is in general, how easy it is to use and also in what scenarios the system could be applied in. The notes of the interview for user test can be checked in Appendix.

Apart from the user tests and interviews, the Vällingby Fire station was also contacted, they were given an explanation of how the product works and what it is supposed to do, in order to truly understand the requirements of a product like this, understanding about the real world scenario in an emergency situation is needed. By getting point of view from the firefighter and their opinions on what information or feedback is of high priority during a situation where a fire inside a building needs to be put out, would be extremely helpful in improving the product and for future work.

According to the firemen of Vällingby fire station, it is important that the system does not need any kind of infrastructure or installation on site since it will be hard to maintain during those circumstances (when a fire breaks out).

The system that this research presented would be beneficial in not all, but some situations. It would not be necessary to track and visualize all kinds of objects in an environment since that is not the biggest concern as they have infrared cameras attached on their helmets and it would not be economically beneficial. But being able to track the movements displacement of bigger and more significant objects or objects that could cause danger if broken would, on the other hand, be very useful. For example objects such as gas tanks or objects that may contain flammable substances. “If it has moved, we would know that something is wrong or that it might have fallen and is leaking”. Being able to track roof planks could also be useful in order to know if the roof has collapsed, but in order to do that, the sensors attached to the roof need to have a high tolerance against heat since the material needs to almost be totally burnt before collapsing. Apart from that, there are some laboratories in the same area that have built smart robots, these robots can move by themselves and are very expensive. So for environments like this, our system would be useful where the objects (robots) could be tracked and visualized on the 3D map. Also when engaging big buildings/castles, they thought that this kind of system would be helpful in locating stairs and different entrances. In a scenario like that, a 3D map combined with a system that can detect the rooms which are on fire and then update the map and point out the locations of those rooms would help the firemen a lot and make their
tasks a lot more effective and less risky. In general, it would be hard to invest in a product that depends on sensors on objects do since there are no statistics of which buildings rooms that have a higher risk of fire accidents. Therefore, the idea of implementing the system in certain buildings is pretty vague. They most certainly do not know where there will be a fire. An optional solution to this problem is a 3D system combined with sensors that could in some way locate the fire inside buildings.

6. Conclusion

In this thesis, the potentiality of a 3D visualized indoor positioning system is explored. The goal of the project is to construct a prototype that would provide position information with detailed 3D display in an indoor environment, as a system that can have the potentiality of working in an emergency situation where other systems face various difficulties. The project reaches a stadium that should satisfy a “proof of concept”, where a 3D environment simulation is updated according to position changes in a real environment where the device being tracked is a smartphone. However, there are several technologies that could be used in order to get the position information. Techniques like GPS and Wi-Fi are popular but have their limitations when used in indoor environments, such as obstacles blocking the signals or requiring a certain kind of infrastructure installed in the environment.

The field of research in this area is pretty new, there are a lot of solutions but not all of them have been investigated by other researchers. There were many factors that needed to be taken into consideration while building the prototype. The main challenges for indoor environments are discussed with the conclusion that a solution based on magnetic positioning was the most suitable in order to demonstrate a possible solution for constructing an indoor positioning program that displays 3D location information of objects, and a smartphone is the most suitable mobile device due to its built-in sensors. The results were as expected and the accuracy of the system was good but the system made some miscalculations in certain positions. The recent advances in embedded sensors in mobile devices open up many new possibilities to improve the indoor positioning systems by taking advantage of these sensors.

6.1 Evaluation of the system

A 3D visualized system that converts real-life coordinates to coordinates in Unity is successfully implemented based on the magnetic positioning system used by IndoorAtlas. The system takes the real-life longitude and latitude to calculates the corresponding coordinates in the unity program. Afterward, the detailed 3D graphic presenting the processed location information is generated accordingly.
The purpose of this thesis is to show how an indoor positioning system could be combined with a software that shows the corresponding positioning information in a 3D display. In order to do that, many different technologies were evaluated and some of them were excluded due to limitations and drawbacks they had in indoor environments during an emergency situation. The main challenges for indoor environments are discussed with the conclusion that fingerprinting techniques based on RSS or Magnetic field are the optimal solutions and that the smartphone with its built-in sensors is the most suitable choice for this projects. These sensors can separately be used in further researches for the purpose of getting the position information. There were many factors that needed to be taken into consideration while building the prototype, and delimitations led us to a solution based on magnetic positioning in order to demonstrate a possible solution for constructing an indoor positioning program the displays 3D location information.

When using magnetic positioning, the material and building structure has an impact on the accuracy of the system. Refraction of the magnetic field on steel structures and large objects indoors creates a magnetic field map that can be obtained and used for positioning, the accuracy will depend on the structure of the indoor environment as it was different for different parts of the building. During the accuracy testing, there are some issues with positioning the object near walls or in narrow corridors. According to the result of the empirical research and the observations, there are some uncertainties where the mobile device that was being positioned seemed to deviate around the actual position or pass through the wall. Apart from that, the test results showed that the system in most cases presents the accurate information and the results are valid.

The idea is a system that should be used in hazardous environments or in environments with objects that have a higher risk. It would be hard to implement this kind of system in every single building for an overall usage since the area that is going to be monitored needs to be mapped beforehand and objects within the area should be equipped with sensors in order to detect movements. Therefore, usage of such a system it should be limited to only hazardous environments and according to feedback from the firemen at the Vällällingby department, this idea is applicable to some extent.

But one thing that is needed to be taken into consideration for this prototype is whether the building materials employed in the construction would create enough high distortions to the magnetic field of the Earth for IndoorAtlas to provide good accuracy. And this could be a problem in buildings where the material consists of stone and wood.
6.2 Summary
With the global positioning system being the most popular positioning system, nowadays, the focus of the related research is moving towards the development of indoor positioning systems. While deploying an indoor positioning technology, the problem of presenting the detailed enough information of positions and the indoor environment has the impact on the practicability of existed indoor positioning systems. In this context, 3D visualization that provides the detailed and immersive visual experience in simulating the environment is proposed as one of the solutions to combine with the modern indoor positioning system. Hence the research question proposed under this background is "How to construct an indoor positioning system that presents the 3D visualized location information."

To verify the possible answer to the research question, the aim of this thesis 3D Visualized Indoor Positioning System is to design and construct a prototype of indoor positioning system visualized with 3D graphics as an experimental system.

The thesis presents both theoretical results of evaluating the practicality of different technical approaches and the experimental result of building a prototype based on the most potential hypothesis. Through the process design of this research, both the learning value and marketing possibility are addressed and evaluated.

The research involves two undergraduate students with background knowledge in Information and Communication Technology. The technical support used in different modules developed through the theoretic background knowledge. By taking the knowledge of various indoor positioning system and 3D construction techniques as references, the working prototype is designed for testing the usability of the idea.

In the experimental system implementation, a mobile application IndoorAtlas utilizing built-in magnetic sensors of the mobile devices to achieve the indoor positioning through a magnetic field. The game engine Unity 3D serves as the software platform for simulating the 3D virtual environment and process the raw position data from detecting. Remote database MySQL is also set up as a tool for storing and transferring the position data.

To validate the prototype, different levels of software testing are taken from unit testing to integration testing. A test case study based on Electrum building in Kista experiment the usability of the prototype in a real situation and examine the functions as a whole system.

The outcome from the experiments presents that combining indoor positioning technology using magnetic field with the 3D game engine to providing the function of 3D visualized position data in an indoor environment is feasible. The prototype fulfills the initial requirements. Therefore, this prototype can be considered as one possible
answer to the research problem though there is a large room for improvement on the performance and user experience of this experimental system.

**6.3 Future work**

This thesis has discussed the importance of detailed location information as context. An overview of different technologies available for indoor positioning is given. The research explores the use of smartphone sensors deeply for localization purposes. More researches have to be done in this field to deal with the technical challenges and limitations of such a positioning system. Meanwhile, the current experimental system is creating the connection among multiple modules in order to achieve the various functions as a whole. Therefore, the work can be extended to a more integrated program which allows the users to operate all the functions of the system under one single and comprehensive user interface.

A future possibility of this research is to explore the sensor based positioning systems in a location where other systems that require infrastructure cannot be established, for example in basements or tunnels. Further studies of how to improve the accuracy of a positioning system combined with a 3D display and adding the height change monitoring function to the positioning system are interesting since accurate position information is of high importance in emergency situations.

The developed concept based on this prototype would be that objects in a room or environment that has a high risk for fire are equipped with a piece of equipment in order to detect if the object has moved from its initial position. To be able to do this as accurate as possible, the equipment should be placed at the center of the object so that the movement detection can be more precise if the object has fallen from its standing position. The system should collect the location information and transfers it to a smartphone application and then to an external database so that the information can be pulled from the database by the software that updates the 3D display accordingly. Thus, the accuracy of the system can be analyzed. The information can then be displayed on a tablet, and so on, at a command center. More research and testing following these principles need to be done to draw even more conclusions about the system and its limitations. Another functionality that proved to be useful and should be added to the system is a heat and alarm sensing functionality. This is essential according to the firemen at Vällinby Fire Station, since locating the fire is the first thing that the firemen do when they enter a building. So for them to be able to locate the fire and get a 3D map over the area would be very useful. For this purpose, a sensor that would sense when the fire alarm goes off and then send the location coordinates so that the fire can be located on the 3D map.
References


74. V. Nagy, “Performance Analysis of Relational Databases, Object-Oriented Databases and ORM Frameworks,” Independent thesis Basic level (degree of Bachelor), University of Skövde, School of Informatics, 2014.


Appendix

Interview regarding user experience with the experimental model:

**Date: 16/08 - 2018**  
**Place:** Electrum, Kista.  
**Interviewer:** Sohrab Alvandian, Ziqi Xia  
**Interviewed:** Payam Karimpur, a student at Department of Computer and Systems Sciences, DSV.

Q: Do you have any earlier experiences with indoor positioning?  
A: No

Q: Is the System easy to use?  
A: The process of positioning is simple but it is a bit hard to use the Unity interface if you don’t get it explained to you.

Q: Does the 3D graphic style give any benefits compared to 2D?  
A: Yes, to introduce the third dimension adds to the quality and preciseness and makes it easier to differentiate between items and distances in a better and more detailed way.

Q: What do you think can be improved?  
A: The accuracy should be improved.

Q: General feedback.  
A: A good prototype with lots of room for further development and improvement.

**Date: 16/08 - 2018**  
**Place:** Electrum, Kista.  
**Interviewer:** Sohrab Alvandian, Ziqi Xia  
**Interviewed:** Rickard Cruz, a student at Royal Institute of Technology, KTH.

Q: Do you have any earlier experiences with indoor positioning?  
A: Only in shopping centers where a path is given from your current position to a certain store.

Q: Is the System easy to use?  
A: Unity is confusing. Apart from that, the different parts of the programs are well connected and it is easy to understand the process.

Q: Does the 3D graphic style give any benefits compared to 2D?  
A: 3D is important when an object is being tracked to see more details, it is also good to see the rooms from different angles and also see the height difference.
Q: What do you think can be improved?
A: Make the interface more user-friendly.

Q: General feedback.
A: Atomization of the system.