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INDOOR POSITIONING SYSTEM RESEARCH AND DEVELOP

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ABSTRACT

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Recently, with the development of GPS which can provide satisfactory positioning outdoor solution, research has turned to the area where the GPS signals could not reach: indoor space of the infrastructure, especially for those huge buildings like shopping malls, airports and museums. Indoor positioning system has become one of the hottest topics in computer science and engineering. Plenty of research resources and funding have poured into this attractive area to find a best solution with satisfaction of accuracy of positioning and acceptable cost.

However, there is not yet one perfect solution in this area for the sake of both less initial hardware investment and accuracy with good satisfaction. To find a solution which requires no initial hardware investment and gains satisfied accuracy, researches on the theory of indoor positioning system was carried out in this thesis. By comparing the existing technologies to realize indoor positioning system, conclusion can be made that geomagnetic localization might be the best hope to provide the perfect solution for indoor positioning.

Based on the theory of geomagnetic localization, with the API provided by IndoorAtlas, an application running on Android platform was developed in this thesis. System architecture and other design details for the software system are also presented. The experiment was conducted on the third floor of Building A in the main campus of TAMK. Evaluation of performance and the result of the application software for the system are also given. The test result for the system shows that the accuracy of the system should be acceptable.

Key words: indoor positioning system, geomagnetic positioning, android application.

CONTENTS

ABBREVIATIONS AND TERMS

GPS	Global Positioning System
IPS	Indoor Positioning System
WiFi	wireless local area network" (WLAN) product based on the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 standards
GNSS	Global Navigation Satellite System
API	Application Program Interface
Android Lollipop	a version of the Android mobile operating system developed by Google
iGPS	intelligent Global Positioning System
WLAN	Wireless Local Area Network

1 INTRODUCTION

From 1990s until recently, large number of papers and thesis on indoor positioning and tracking has been published in this area and indoor positioning has been becoming a hot topic in both academic and industry. With the development of smart phones, numerous applications on mobile devices provided for the users in shopping malls and other large infrastructures like airports and museums have been produced and started to come into the stage of commercialization. Since the year 2010, some of the products even have attracted adventure investments and gain some business success in the markets.

1.1 Definition of indoor positioning system

According to the definition of Kevin et al. (2011, 61-78), an IPS is a system to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices. From this definition, IPS should be able to collect the data of the sensory from the mobile devices. One critical thing, which identifies the outdoor location system like GPS, is that it is used indoor environment, inside a building. Of course, the most important task of it is to determine the position of the objects or people.

1.2 The motivations for indoor positioning system

As it is known, principle of GPS (Global Positioning System) is based on calculation of the radio signal transited and received by multiple satellites in the air. There are three segments which comprise the whole system of GPS: space segment that contain the satellites, control segment that is the monitor station on land and user segment that are the receivers which receive and interpret radio signals broadcast by the satellites (Wikipedia Global, Positioning System, 2015). The prerequisite of positioning is that the ground receiver can receive the radio signals with carrier frequency of 1.57542G Hz which is called L1 Signal or 1.22760G Hz which is called L2 Signal from the satellites orbiting in the air (Wikipedia, Global Positioning System, 2015). These GPS signals with such frequency and weak power make them difficult to penetrate the buildings made of walls, roofs, floors and concretes. Even with some amplifiers to enlarge the strength of the radio signals, some of them might pass through, the signals might be distorted and the receiver would interpret them with unacceptable errors. So GPS with the positioning accuracy of

10 meters outdoors doesn't work properly indoors, especially inside the buildings of sky-scrapers and underground infrastructures, where the shelters are thick enough to alter the path of GPS signals or even block them thoroughly (Wikipedia, Global Positioning System, 2015).

The reasons why people want to discovery the indoors area where GPS could not cover and what drives people to develop indoor positioning, tracking and navigating system can be found here:

Firstly, successful commercial applications of GPS bring billions dollars and millions jobs, the same thing will probably happen on indoor positioning as well. Significantly, it can be seen that there are huge commercial and military benefits from the GPS. From this report (Nam 2011, 1-15), it can be seen that the direct economic benefits of GPS technology on commercial GPS users are estimated to be over $67.6 billion and would increase to $122.4 billion per year in the United States in 2010. Further, 3.3 million jobs are created from GPS technology. (Nam. 2011, 1-15.) Nowadays, people seem to live without GPS which is widely used in the fields of Ground transport, aviation, machine control, marine, people-tracking, precision Ag, railway, surveying/mapping, timing/synchronization, automobile, converged, recreational and military. (Nam. 2011, 1-15.)

After GPS, indoor positioning system is considered to be another gold mine in the future. There are huge benefits for the indoor positioning applications. The needs for indoor positioning system are illustrated by the following scenarios (Li 2014):

1) Shopping mall scenario:

Nancy, age 23, is an office lady in an IT company. She is crazy on shopping even though she does not have high salary. Her frequency of going shopping is twice or three times per week. But she always gets lost even she has visited that shopping mall frequently. Meanwhile, she has an app installed which has the function of indoor positioning and provides the exact sales information such as the discount information and recommends the best sellers for her. She always relies on the app to lead her way to the destination just by inputting the simple and necessary information through the UI interface. On the way to the destination, she can also get plenty information about the goods she wants from the indoor positioning app. Once she likes to stop to purchase something, the app can even show her the products price information of other brands for her reference. Information keeps on showing until she reaches her destination or she cancels her order for the app. When her friend Kelly comes to meet her and join her to go shopping, with inputting the position of the meeting place they both agree with, the app then guides Nancy the best way to meet Kelly without getting lost. She always enjoys the app and thinks it a fantastic tool to help her to enjoy the time in the shopping mall.

2) Children tracking scenario:

Jenny, who is three years old, travels with her father in the international airport with the area of millions of square meters. Jenny is told to stay still outside the toilet for men because her father needs to go into it. But Jenny is attracted by an event held on the hall of lower floor. She forgets what her father told her and cannot wait to see the show there. Two minutes later, Jenny’s father goes outside from the toilet and he looks around but cannot find his daughter. Then he takes out his mobile phone and turns on the app which has tracking function. The app tells him the position of his daughter who is on the lower floor on the hall. Then he follows the tracking information and very quickly finds his daughter Jenny. He really thanks and appreciates that app. Without the tracking software installed on his phone and the special watch wearing on his daughter, he could not get his daughter in such a short time. Then he takes out his mobile phone again, has a scan for their air tickets, then the app shows him the way to the check in entrance.

3) Car parking scenario:

Tom, who is a staff of TALT locating in ALT building, has to drive his car daily from his home to the office. Parking lot in ALT building where accommodates thousands of vehicles at the same time lies in underground floors. When Tom drives his car entering the car park, he takes out his smart phone which has installed the app provided by the manage department of the parking lot. The app of indoor positioning system can tell the exact location of his car and provide the navigation service for his car to the place available. Following the guide of the app, Tom could immediately find a place to park and then heads towards the nearest lift to his office indicated by the app.

These are the only some of the typical scenarios which indoor positioning will bring us. Though there are not tons of studies found on the impact of the indoor positioning system, we could predict from GPS and these scenarios that indoor positioning system will bring us large amount of benefits that beyond our imaginations and maybe billions of dollars, jobs and other non-commercial benefices. That is why such great deal of money and stuffs have been concentrating on this area.

1.3 Challenges of indoor positioning system

There are some indoor positioning systems that claim to realize the accuracy of millimeter like coordinate measuring machine, laser tracker, and iGPS (Rainer 2009, 18-22). However, they usually require sophisticated infrastructures and expensive instruments which lead to high cost. And they have limited coverage area or manual setup of a large sized takes too much time and costs huge resources consumption.

On the other hand, other systems that cost less and with less sophisticated infrastructure cannot achieve satisfactory accuracy and they are not able to be deployed in most cases and found no way to commercialize.

The challenge of researching and developing indoor positioning systems, in one word, is to find a best system with the highest accuracy, least setup time and cost and least operation consumption.

1.4 Contributions of this thesis

One of the most important aspect of this thesis is to compare and evaluate the existing technologies and methods for indoor positioning. By comparing the strength and weakness, it can be seen that magnetic localization might be the most prospective solution. Therefore, this technology is chosen and used in application development. Another significant work of this thesis is the implement and development of magnetic localization: an app running on Android is developed. Designing and testing for the system would be the most valuable part for software engineering.

1.5 Outline of this thesis

This thesis, which is for the fulfillment of master degree in information technology, will present the researches of varies of indoor positioning systems and focus on one of the innovated ways of realization: the magnetic localization. In chapter two, basic principles of indoor positioning systems, including the most attractive ones recently: WiFi and Bluetooth technology and other popular systems will be given. Both the merits and weakness of these systems are going to be analyzed in this chapter. Chapter three will illustrate the principle of the technology of using the earth's geomagnetic field to find locations, which is recognized to be the most competitive method of indoor positioning. Since this master degree focuses on software engineering, software development is the key point here. So the following chapter, an app running on Android will be proposed and shown. System architecture and structure of the app will be highlight in chapter four. Performance and evaluation for the app application will be demonstrated in this chapter as well. Chapter five will be the summary for the entire project and thesis. Last chapter will suggest for the future work of the app application and this thesis.

2 OVERVIEW OF EXISTING TECHNOLOGIES FOR INDOOR POSITIONING

2.1 Categories of the existing technologies

Based on the sensors, there are a number of technologies and methods to realize the function of indoor positioning. Some scholars even divide them into 13 different technologies (Rainer, 2012, 9-10). Indeed, some of them can be merged since they have the similar principles. Here, these technologies can be divided into eight categories, which is shown in table 1.

TABLE 1. Categories of the existing technologies. (Rainer, 2012, 9-10)

Technology	Typical Accuracy	Typical Coverage (m)	Typical Measuring principle	Typical application
WLAN/WiFi /Blue Tooth	m	20-50	fingerprinting	pedestrian navigation, location based service
Radio	cm-m	1-1000	proximity detection, fingerprinting, body reflection, time of arrival	pedestrian navigation, robotics, automation
cameras	0.1m m-dm	1-10	angle measurements from images	metrology, robot navigation
infrared	cm-m	1-5	thermal imaging, active beacons	people detection and tracking
sound	cm	2-10	distance from time of arrival	hospitals, tracking
High sensitive GNSS	10m	'global'	parallel correlation, assistant GPS	location based services
Magnetic system	mm-cm	1-20	fingerprinting and ranging	hospitals, mines, pedestrian navigation
Tactile& Polar Systems	um-mm	3-2000	mechanical, interferometry	automotive, metrology

From table 1, it can be seen that all the existing technologies mainly rely on two kinds of mediums: electromagnetic waves and a few on mechanical (sound) waves (Rainer, 2012, 9-10). And it can be easily found that some methods like sound, infrared, cameras, magnetic system, tactile& polar systems, and magnetic system can even achieve the accuracy level up to mm, which could be able to fulfil the requirements of most demanding applications.

But in fact, until recently, most of the commercial applications available on the market rely on WLAN/WiFi plus Bluetooth technologies which have relatively lower accuracy and larger coverage area comparing to other approaches. The most important factors needed to be considered for this should be the initial hardware investment and the convenience of hardware deployment. WLAN/WiFi and Blue tooth technologies normally does not require to any extra hardware investments and change the structure or anything else inside the buildings. The end users could just use their mobile phones which are owned by everyone to access the service of location or tracking. While other technologies need to change a lot on the existing building and invest extra resources to provide the services. These are the reasons why WLAN/WiFi and Blue tooth technologies are popular and wins in the competition with other technologies in the commercial market. The following sections will introduce more about these technologies, especially the one based on WLAN/WiFi and Blue tooth.

2.2 Indoor Positioning based on WLAN/WiFi

2.2.1 Current situation on WLAN/WiFi

As indicated in the previous section, there are already numerous of commercial applications available on the market. From table 2 which lists a great number of applications available on the market, obviously it can be seen that indoor positioning based on WLAN/WiFi technology have been widely existing. All of these can be downloaded from Google Play app market. Some of these apps are also available both on Google Play and iOS platform. Some of these apps combine multiple technologies, such as WiFi, GPS, mobile phone signal and Bluetooth according the introduction from their websites or the product guides. But they all claim to use WiFi technology as their main approach.

From these applications, apparently, the indoor positioning based on WLAN/WiFi is in prosperity and it seems to be the domain technology which provides the services at this stage. But the real situation of the accuracy of those products and the marketing statistics report have not been found yet.

2.2.2 Principle of WLAN/WiFi indoor positioning

For the WLAN/Wifi system, there are various of measurements for the calculating of the position: TOA (Time-of-arrival), TDOA (Time-difference-arrival), AOA (Angle-of-arrival) and WLAN (Wireless Local Area Network) RSS (Received Signal Strength) (Dru & Saada 2001; Liu et al. 2007). Among these techniques, focus of research has turned to WLAN RSS technique as it relies on IEEE 802.11 principle which has become the industrial standard and massively deployed. With the tremendous development of portable and mobile devices which embedded WLAN system as basic equipment, WLAN RSS has taken the advantage. (Jiang 2012, 2-3.)

Basically, WLAN RSS is comprised with five fundamental strategies to calculate the distance: strongest base station, cell of origin, propagation modelling, fingerprinting based and multilateration (Rainer 2012, 58).

Among these strategies, strategy of multilateration is indeed defined by combining the multiple methods of RSSI (Received Signal Strength Indicators), TOA, TDoA, AOA and RTT (Round Trip Time) to calculate or estimate the distance between the transmitters and the receivers. Receivers got the information which contains the arrival times and the amplitudes to calculate the distance in the form of waveforms from the transmitters. These all are carried out from the IEEE 802.11 standard protocol to measure the path loss to determine the distance. (Rainer, 2012, 61-65.)

In order to determine the Received Signal Strength Indicators, fingerprinting methods that implement premeasured location related data offline, so called empirical fingerprinting, are usually used. There are mainly two phases in fingerprinting approaches: offline training phase and online positioning determination phase. First, signal strength distribution from the access points at predefined reference points that are called fingerprints in the operation area are collected and stored together with their physical coordinate in a database. Then, during the online training phase, software on mobile devices or severs sample the signal strength of access points in communication range and search for similar patterns or match data in the database. After comparing, the closest match is selected and its coordinate is returned to the mobile device as a position estimate of the position to show out. (Thomas et al. 2006.)

There have been a couple of systems or projects that adopt the method of fingerprinting, listed in table 2.

TABLE 2. Some WLAN location determination systems based on fingerprint.

Name of the system	Principle	Merits or limitation
Daedalus project	Based on coarse-grained user location. A mobile host estimates to be the same as the base station to which it is attached. (Hodes et al. 1997.)	The accuracy is limited by the access point density (Hodes et al. 1997).
RADAR system	RF signal strength is used as an indication of the distance between the transmitter and receiver (Bahl et al. 2000).	Cost-effective. Median resolution is 2-3 m. Long time to gather all the empirical data. If base station moves, all the data have to be recollected. (Bahl et al. 2000.)
Aura system	Pattern matching (PM) and triangulation, mapping and interpolation (TMI) are used to determine of the location. (Smailagic et al. 2001.)	Use less power than previous model and gain more security privacy. (Smailagic et al. 2001.)
System based on Bayesian inversion	Signal strength histograms is stored in the radio map and used in the online phase to estimate the user location (Castro et al. 2001; Roos et al. 2002).	Average location estimation error less than 2 meters (Castro et al. 2001; Roos et al. 2002).
Horus system	Different causes for the wireless channel variations are identified and addressed to achieve its high accuracy. Location-clustering techniques are used to reduce the computational requirements of the algorithm (Moustafa & Ashok 2002).	Average error less than 0.6 m. Less computational requirements. It can be applied to other WLAN location determination systems to enhance their accuracy. (Moustafa & Ashok 2002.)

It seems that, from the experiment results, all of these systems claimed to achieve acceptable or even satisfied accuracy. For example, average error of Horus system can be even less than 0.6m. However, all of them only work in lab or experiment environment. The following section, commercial used software systems will be provided.

2.2.3 Commercial use of WLAN/WiFi systems

The apps which belongs to WLAN/Wifi systems are listed on table 3 although they do not indicate which methods/Algorithms or names of the APIs they adopt in their products.

TABLE 3. Existing apps that can be downloaded from Google Play store.

Name of the app	Owner	Published year
Indoor Positioning System	Nikolaos Papadakis (a COEN 490 capstone project for Concordia University)	April 1, 2011
WiFi Indoor Localization	Hfalan	February 17, 2014
Indoor Positioning System	Petra Christian University	June 2, 2014
Crux Indoor Location	South Mobile	July 21, 2013
Indoor GPS	LadiesMan217	December 19, 2014
BuildNGO - Indoor Navi	SAILS Technology	November 16, 2014
Wifarer Indoor Navigator	Wifarer Inc.	October 9, 2014
Contagt	Contagt GmbH	November 5, 2014
Indoor positioning	Bao	October 28, 2013
30C3 Indoor-Navigation	Tarent AG	December 25, 2013
Funwalk-indoor map	Beijing SIWEITUXIN tech LTD.	March 24, 2014
Calibration	Infsoft GmbH	November 9, 2014
IMap	Sails technology	February 25, 2014
WifiPosition	Evgeniy Yanev	March 19, 2012
SOS Pro by Automagi	AutoMagi Ltd.	January 26, 2014
Location Tracker	Kim and Yang	June 3, 2014
AGILE2014	Ubik Geospatial Solutions	June 3, 2014
MazeMap	Maze Map	August 5, 2014
LINE Maps for Indoor	LINE Corporation	December 22, 2014

Some of these apps are developed by companies and they have gained some adventure investment to expand the market. For example, a company called Sails technology listed above has provided the service to some hotels and car park centre to maintain their operations.

2.2.4 Merits and weakness of WLAN/WiFi indoor positioning

It can be easily seen that indoor positioning systems based on WLAN/WiFi is a cost effective solution that only requires existing infrastructures. So it does not need any initial and extra hardware investments. With large amount of research and develop pouring into this area, the accuracy of this method has become acceptable or even satisfied. However, because some of the characteristic of WiFi signals, the attenuation by human body or other obstacles and varies of hotspots might have grave effects on the accuracy of the positioning. In sum, for the indoor environments which are cost sensitive and not in high accuracy requirement, WLAN/WiFi system would be a good choice for implementing the function of positioning and tracking.

2.3 Indoor Positioning based on Bluetooth

2.3.1 Principle of Bluetooth positioning indoor positioning

Nowadays, along with WiFi, Bluetooth techniques are two popular methods that are considered to be cost effective and some of which have come into the stage of commercialization. In order to compensate the weakness of WLAN/WiFi, it is natural that researchers and engineers use Bluetooth to integrate with WLAN to find a more perfect system.

Bluetooth is a technology that uses radio frequency between 2.402 GHz and 2.480 GHz to communicate among the electronic devices in the areas of industrial, scientific, entertainment. Cell of Origin method can be implemented as the basic positioning principle for Bluetooth while other methods such as time-of-flight while RSSI are not considered to be suitable and reliable options for positioning due to the standards and intrinsic characteristics of the Bluetooth protocol: there is no direct relationship between the signal strength and the distance. (Aalto et al. 2004; Anja 2012; Cheung et al. 2006; Hossain & Soh 2007.)

In Bluetooth, triangulation and fingerprinting are the two main techniques used to indoor positioning. As indicating in the article from Hossain & Soh (2007), the Bluetooth signal parameters used in triangulation are not sufficiently accurate (Hossain & Soh 2007). Therefore, like WLAN/WiFi, fingerprinting based on radio map is widely used in Bluetooth positioning. This means that there are also two phases for setting up the Bluetooth method: Offline phase to collect points containing the RSSI received from beacons and the online phase to compare the measured points with those in the pre-recorded fingerprints in the database to find the most closed sample vector as the estimated position given (Anja 2012).

It is not that simple to compare the measured points with the pre-recorded fingerprints. There have been several algorithms such as probabilistic and deterministic as two categories proposed for predicting positions from a radio map. And probabilistic algorithm occupies large portion of the research yet weighted k-Nearest Neighbor algorithm is the most commonly used and can give not only fairly good but also similar results. (Mikkel 2010.)

2.3.2 Commercial use of Bluetooth indoor positioning systems

Table 4 lists two of the commercial Bluetooth indoor positioning systems which only based on Bluetooth signals (Ionut et al. 2010; Anthea et al. 2010).

TABLE 4. Some Commercial Bluetooth indoor positioning systems

Name of the system	Owner	Feature
ZONITH Indoor Positioning Module	Teldio	Consists of ZONITH Bluetooth Position Beacons to track any Bluetooth-enabled mobile devices that enter the area. It is used for monitoring employees working in hazardous environments. It can provide room-level accuracy. (Teldio 2010.)
Waspmote Bluetooth Radio	Libelium	It is programmable and there is a module mounted on their Waspmote sensor board and has been used as part of their traffic monitoring platform. (Libelium Comunicaciones Distribuidas 2015.)

2.3.3 Merits and weakness for Bluetooth indoor positioning systems

Like WLAN/WiFi system, indoor positioning systems based on Bluetooth/Beacons technology is considered to be a low cost and easy to deploy method among the indoors positioning methods. But obviously, due to its intrinsic weakness of positioning in its protocol, this technology has not attracted as much attentions as WLAN/WiFi positioning system, and commercialization for it is less competitive as WLAN/WiFi positioning system. But since it has the advantage of low cost and can use the of-the-shelf infrastructures, it can be used as complement for WLAN/WiFi indoor positioning system to improve the accuracy.

2.4 Other indoor positioning systems

Besides the WLAN/WiFi and Bluetooth which has become commercial products, other existing indoor positioning systems seem actually have not saw gain practical commercial utilization. The reason can be easily guessed that they need to deploy extra instruments thus take extra investments and even need to change or update the of-the-shelf infrastructure of the buildings or they could not attain competitive accuracy. For example, technology used infrared claim to achieve the accuracy of cm or even mm grade, but they have to conduct large amounts of measurements and need to install the transceivers and receivers, and they also need to upgrade the lighting system to add the infrared light system. (Rainer 2012.) And in most of the scenarios, accuracy of cm or mm are not needed.

2.5 Conclusion for this chapter

In this chapter, principles for the popular existing indoor positioning approaches are introduced. Commercial products for the indoor positioning systems are given. Two mainstream indoor positioning technologies: WLAN/WiFi and Bluetooth are described in detail. By showing their merits and weakness, it can be seen that none of these technologies or methods can perfectly realize the task of indoor positioning in terms of cost, complexity and accuracy although they are supported by some industrial giants such as Google, Microsoft, Apple. Hence, it is natural to find a better way to realize indoor positioning system with less cost, and higher accuracy. Indoor positioning based on Geomagnetic might be the most prospective technology to win the game.

3 INDOOR POSITIONING BASED ON GEOMAGNETIC

3.1 Principle for geomagnetic localization

Decades ago, researchers like Mourisen et.al. have proven the fact that birds and other animals are able to use magnetic fields for orientation for themselves (Wiltschko & Wiltschko 1972). There are two kinds of magnetic information: direction of the magnetic field lines which can provide the reference direction for a magnetic compass and changes in intensity and/or inclination angle which can provide positional information in the form of magnetic 'signposts' or a full magnetic map. (Henrik & Thorsten 2005.)

Inspired by the orientation mechanism of these animals, experts and researchers try to find a way to simulate the birds and those animals in orientation for human beings. As it is known, our earth itself is a huge magnetic field, compasses or magnetometers can be used to detect the direction. Meanwhile, there are large amount of man-made magnetic such as electromagnetic produced by electronic and electrical power lines. (Haverinen & Kemppainen 2009; Anastasia et al. 2005.) In addition to this, when it comes to inside the building environment, distortions of the magnetic field significantly come from the steel and concrete skeletons (Jaewoo et al. 2011). These kinds of man-made magnetic can intervene the natural magnetic field of the earth to some extent according to their intensity. The interference from the man-made magnetic produces the distortions on the compass and cause errors from the ground truth directions. Since the distortion and errors are constant in certain locations, a pattern map of fingerprint can be made by training or calibration and the result data can be stored in the form of database. (Haverinen & Kemppainen 2009.) With the real time measurement of the magnetic flux which is to be compared with the fingerprint stored in the database, real time location can be determined if the proper real time data matches the fingerprint database. (Dries et al. 2013.)

To make the indoor location with geomagnetic feasible, it must meet the requirements of the following (Li et al. 2012): First of all, the density of the magnetic flux must be stable in the certain point and constant over a long period of time. If it is unstable and changing all the time for the certain points, it makes no sense to make the finger print map and it is impossible to compare it with the real time data. Secondly, the errors or distinction of the magnetic density among different points must be noticeable and significantly, otherwise, it is not implementable to figure out the distinctions and match the right points with the same flux density of the magnetic. Even the distinction of the magnetic density is not large enough, the accuracy of the position cannot be promised, otherwise, this technology would not have much competition with other indoor positioning technologies like WiFi and Bluetooth described in the previous chapters. (Dries et al. 2013.) For example, if there are two area with similar flux density, the system cannot figure out and judge the differences and probably confusion of location will come out.

From Figure1 and Figure 2, it can be seen that the magnetic field inside a building can be measured and recorded. Meanwhile it presents variations of magnetic flux density among different locations although magnetic map is not unique in every given location, algorithms can be applied to acquire position when objects or pedestrians move through every points in the map.

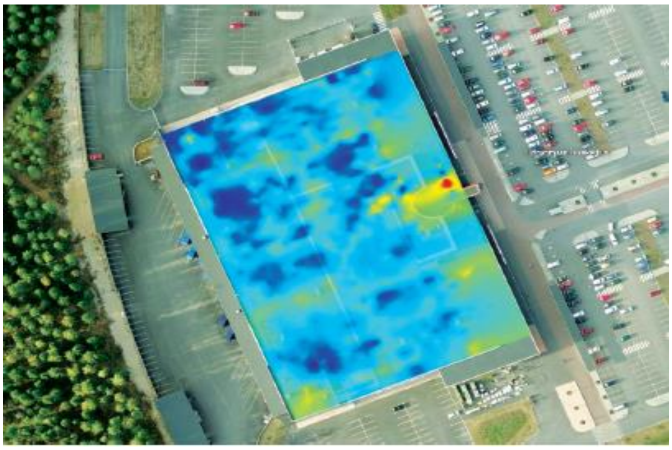

FIGURE 1. Magnetic Field inside a Building, source from IndoorAtlas (IndoorAtlas Ltd. 2012)

FIGURE 2. Magnetic Field of Time Warner Centre, New York, US, June 2012. (IndoorAtlas Ltd. 2012)

First key problem for the indoor location with geomagnetic comes from the fingerprint map of the indoor magnetic anomalies premeasured. It has been proved by Dries Vandermeulen et al. (2013) that inferences including presence of external metal or other electronic distortion, contact of human hands which were called soft iron effects do not have significant effects on the test results while hard iron effects which are caused by the internal structure of the sensor and can be compensated and calibrated, as well as objects placed indoor environments depending on the size and magnetic composition, have considerable effects on the measurement (Dries et al. 2013).That is to say, for the soft iron effects, inference from larger objects, comparing to the room, cannot always be ignored while influence from relatively smaller objects can be can be considered to be negligible. Filters also needed to apply when collecting the signatures which might be affected by the noises produced by the factors mentioned above. (Dries et al. 2013.)

In terms of fingerprint collected, concerning locating in different floors that are different height of the location, Navarro and Benet (2009) also extended the idea of magnetic mapping to a two-dimensional area, using a single magnetic compass that measured in one plane (Navarro & Benet 2009). This makes the feasibility for location of various floors.

Like WiFi or other indoor positioning technics, the matching of the fingerprints also needs effective algorithms to promote the accuracy of the data comparisons. Timothy et al. (2011) proposed and developed two algorithms that are the Windowed Cost Minimization Method which uses a least-square cost minimization to score comparisons between the follower window and a candidate master window and the Dynamic Time Warp (DTW) which is part of the Continuous Processing Method (CPM) algorithms that seeks to align sets of data by both index and time. Both of the algorithms can achieve the accuracy of approximately 1m of time errors in four experimental locations. (Timothy et al. 2011; Listgarten et al. 2005, 2007.)

Plenty of experiments have been conducted to verify that it is applicable to use the magnetic to locate the position for indoor environment (Dries et al. 2013; Flora et al. 2005; Jaewoo et al. 2011; Haverinen & Kemppainen 2009; Saxena & Zawodniok 2014; Timothy et al. 2011). It has also been proved by the experiments that all of the above the requirements mentioned can be met with geomagnetic measurement. Not only can this technic can be used as indoor positioning, but also it can achieve high positioning accuracy. System developed by Jaewoo Chung et al. (2011) from MIT can even achieve the result of ‘the potential to not only locate people in a building at the meter scale, but also at the center meter scale’. It can achieve the accuracy of 4.7m and precision with 90% within 1.64m or 50% within 0.71m (Jaewoo et al. 2011). Researchers from computer science and engineering laboratory in university of Oulu, Finland (Ilari et al. 2010; Haverinen & Kemppainen 2009) proposed the localization and mapping (SLAM) method and global self-localization technic to utilize the anomalies of the ambient magnetic field. Further they developed a practical system and even made it as commercial application. The system in this thesis is developed based on the fulfillment of their research and technique (Ilari et al. 2010; Haverinen & Kemppainen 2009). The application will be introduced in detail in the following chapters.

3.2 Applications based on the theory of ambient geomagnetic localization

Based on the theory of geomagnetic location, there are some systems that have been proposed and developed, some are even based on mobile phones or tablets which are widely used in modern society. Among these systems are shown in table 5. It has shown all the systems that have been found which are all based on ambient geomagnetic location.

Obviously, there are less systems rely on this technology available. Published paper and search materials are also relatively less comparing to those of Wifi and Bluetooth technology.

The first four systems listed above are laboratory-based systems that are not in practical use. The last two systems are the systems which have been tested in the practical application environment. And for the last two systems, the one developed by Makkonen et al. (2014) is actually derived from IndoorAtlas while application field is in the mines underground. In addition to application environment of retail and mines, IndoorAtlas says its applications could be used to guide rescue efforts, museum tours, airports passengers or navigation for the blind (IndoorAtlas Ltd. 2012).

According to the report from Opus Research, currently, IndoorAtlas is the only company which deploys and commercializes the ambient geomagnetic technology into market according to Greg (2014). This might be the reason why Published paper and search materials are also relatively less comparing to those of Wifi and Bluetooth technology.

TABLE 5. Systems based on ambient geomagnetic location

Name of the system	Developer	Feature
Magnetic Field for Indoor localization on a Mobile phone	Andreas Bilke and Jurgen Sieck	Magnetic field and light intensity fingerprints are used. An arithmetic mean error of 4.1 m was attained in an office environment with a particle filter applied to the system to improve the accuracy. (Andreas & Jurgen 2013.)
Indoor Location Sensing Using Geo-Magnetism	Jaewoo Chung et al.	Positioning Algorithm adapted with Nearest Neighborhood with least RMS. Accuracy within 1 meter 88% of the time in experiments in two buildings and across multiple floors within the buildings. (Jaewoo et al. 2011.)
A geomagnetic field based positioning technique for the underground mines	Haverinen and Kemppainen	Made a positioning test underground with an accuracy of about 1.5 meters. (Haverinen & Kemppainen, 2011.)
The Applicability of a Geomagnetic Field based Positioning Technique with Mobile Phone to Underground Tunnels	T. Makkonen, R. Heikkilä, A. Kaaranka	It is an IndoorAtlas based system used in the mines environments.The application has been tested and measured in the Outokumpu Kemi mine which is a chromium mine with about 500 meters depth below the surface. (Makkonen et al. 2014.)
IndoorAtlas	Haverinen et al.	A commercialized indoor positioning system used in universal environments. (IndoorAtlas Ltd. 2012.)

3.3 IndoorAltlas' technology utilized on Indoor Positioning

In July 2012, based on the researches and development done by Janne Haverinen and other funders, a start-up company called IndoorAltlas has been set up to move the ambient magnetic field-based technology from the lab to business. It claims to be a software-only system that requires no extra infrastructures like Beacons used in blue-tooth technology. What it requires is only the smartphones with built in sensors including accelerometer, gyro and compass or magnetometer which are available on most of the modern mobile devices.

The core technology from IndoorAltlas to indoor positioning is to compute, compare and match the sensor data collected from smart devices with the signatures previously processed and collected from the API and stored in the cloud sever provided from IndoorAtlas, and then send back the location information with the floor plan of the venue to the smart devices. IndoorAtlas also provides the tool called *IndoorAtlas Map Creator*™ to create the magnetic field data map which can be uploaded and updated on Microsoft's Windows Azure cloud platform. So all what is need to set up an ambient magnetic based location system on IndoorAtlas with the accuracy ranges from 0.1 meter to 2 meter (IndoorAtlas Ltd. 2012) is just a smart device that can be connected to the host server built by IndoorAtlas. Therefore, it is considered to be a cost-effective, easy to use technology from the points of views of both of the developers and the users.

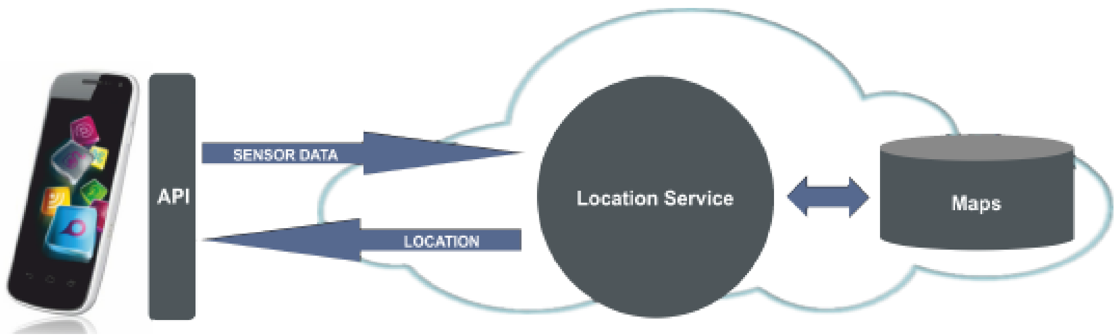

FIGURE 3. Illustrations on the process of ambient magnetic location system based on IndoorAtlas technology (IndoorAtlas Ltd. 2012).

3.4 Conclusion for this chapter

In this chapter, principles for geomagnetic location technology are introduced and explained. Feasibility of application of ambient magnetic has been studied and proposed. Some solutions for the technics are also presented. By listing the application system used with ambient geomagnetic location, it can be seen that in lab environment, this technology can achieve acceptable accuracy, while there are not numerous systems developed comparing to the WLAN/WiFi systems. Meanwhile commercial products based on this technology can only be found from IndoorAtlas. Basic illustrations to IndoorAtlas system is also given in this chapter.

4 DESIGN OF THE INDOOR POSITIONING SYSTEM BASED ON INDOORATLAS TECHNOLOGY

4.1 Preliminary design of the indoor positioning system

As indicated in the previous chapter, indoor positioning based on ambient geomagnetic is considered to be most prospected technologies among the indoor positioning systems because the initial infrastructures of hardware investments on the system are not needed and its attractive accuracy which made it possibility of being the best solution on indoor positioning. Since IndoorAtlas has provided the SDK and the floor plan creator, the burden for the task of indoor positioning system based on ambient geomagnetic is less heavy. So the project created for indoor positioning system based on ambient geomagnetic will focus on the software design aspect.

For the project, a SDK which implements IndoorAltlas API has been developed on Android system. The application can first load the floor plan for on third floor of building A in TAMK main campus which is used as test environment. It can realize the function of showing the location of the pedestrian who is running the APP with Android devices. When moving on the floor, the blue dot indicating the location will follow the variations of the locations so that the users are able to know the position within the whole building. The following paragraphs will explain the design procedures and details of the APP step by step.

4.1.1 Tools and environments for development on the project

The precision and quality of the sensor for the smart phones play a pivotal role in accuracy for the positioning (IndoorAtlas Ltd. 2012). According to the user guide of IndoorAtlas, IndoorAtlas recommending devices for mapping include Nexus 4, 5 and 6, LG G3 and G4, Xiaomi Mi4 and Samsung Galaxy S4, S5 and S6 (Elina 2015a). It has reported some known issues that Nexus 7 which was 2012 model is not recommended due to low sensor accuracy (Elina 2015a). Therefore, in order to attain satisfied accuracy, a high solution of mobile devices has been selected for the development and test: Samsung Galaxy 5 16G with ART code SM-G900FZKANEE, although it is not the most advanced devices at the moment. But indeed, this model is recommended by IndoorAtlas as test mobile devices as well.

From the product specifications for the Samsung galaxy 5, it can be seen that: sensors included are: Accelerometer, Gyro, Proximity, Compass, Barometer, Hall, RGB ambient light, Gesture, Fingerprint, Heart Rate Sensor (SAMSUNG ELECTRONICS CO., LTD. 2014). The detail information for the accelerometer, Gyro and compass which are the most concerned sensors in the project cannot be found on the published material of Samsung, but they can be tested by entering some secret codes like *#12580*369# and *#0*# to the normal dialling keypad. Information of the phone like software version of Samsung Galaxy S5 can be known as well: AP/CP: G900FXXU1BOB7, CSC: G900FNEE1BOB1. And HW REV is: MP 1.100 (SamsungSFour.com 2015).

There is also operation system version requirement for Android. From the user guide of IndoorAtlas, the requirement for the Android system is Android 4.3 and above. That might be due to the requirements from the API of the Android operating systems since some of the APIs were obsoleted in the older version of Android systems. For the operating system used in this project, it would be Android 5.0 Lollipop which was updated on November, 2014. So it completely meets the requirement from the user guide.

The development environment for the project is: Android studio 1.1. And the version of the IndoorAtlas SDK is Android SDK 1.4.2-132 which is the latest one so far.

4.1.2 Steps for creating the floor plan

From the user guide of IndoorAtlas, the first of all, the PNG format file for the floor plan image that is layout of the venue is needed. The PNG format file can be attained from accurate venue blueprint converted from CAD file or a simple image of the floor plan drawn by hand or the photo taken from the office’s evacuation plan (Elina 2015a). In this project, the layout of building A which is exactly the drawing of the building in CAD format is provided by the engineering department of the campus of Tampere University of Apply Science (TAMK). So the proportion of the drawing is exactly the same as the real situation.

Then the PNG format file of the floor plan is uploaded to the IndoorAtlas Maps which is map system similar to Here map system. Accessing into map creator system, one must register as developer user on the website of IndoorAtlas. Adding new venue provides the function of adding the corresponding images on the destination floor plan. When placing the floor plan on the corresponding map, floor plan uploaded has to be in right scale and aligned with the layout shown in the map system (Elina 2015a). Figure 4 shows the floor plan for the A building of TAMK. The floor plan can be saved on the server of IndoorAtlas with Floorplanid, Floorid, Venueid, Map status and Geocoordinates which are generated by the system. These IDs can be used to connect the mobile devices with cloud server when downloading the floor plan is needed.

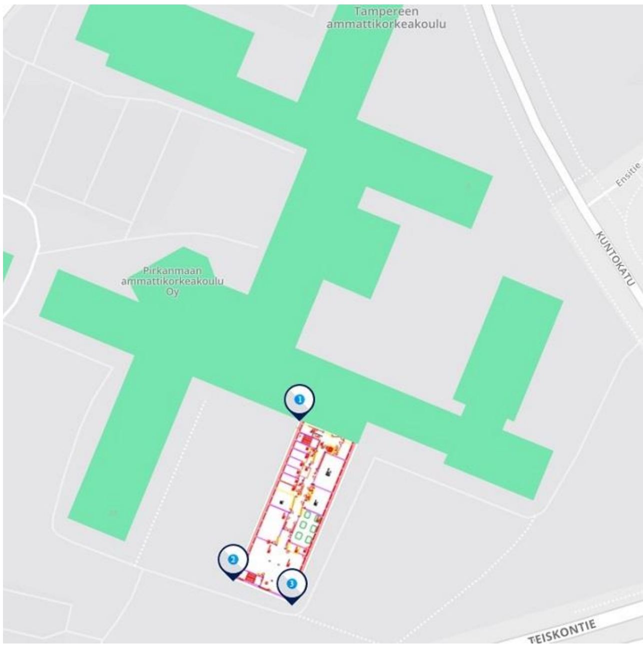

FIGURE 4. Floor Plan for the A building of TAMK

The next step comes the mapping procedure. As indicated in the previous paragraph, Samsung Galaxy S5 contains three kinds of sensors: accelerometer, gyroscope and compass which also meet the requirement of sensor accuracy for mapping. As well as the fact that Android system supports WiFi scanning which is recommended by IndoorAtlas (Elina 2015a). Samsung Galaxy S5 deployed in the project is utilized to create the map for building of TAMK. For the this phase which does not support floor switch, mapping for only the third floor of building A has been created and tested.

MapCreator, an application provided by IndoorAtlas can be used as the tool for calibration for the sensors, creating the maps and testing positioning. Following the instructions of mapping on the guide of IndoorAtlas (Elina, 2015a), sensor data of a path on the corridor can be recorded and uploaded to the server of IndoorAtlas as a map containing the geomagnetic fingerprint information. For this project, map for third floor of building A in TAMK has been created shown in Figure 5. Pictures for the actual indoor environment in third floor of building A in TAMK campus are shown in appendix 2. Main paths which are dark blue lines with arrows are made in the corridor and the room A3-20 where there are six large tables shown in Green. Noticing that on each table, there are four computers which would produce magnetic that might take some effects on the location. Since the principle of magnetic location is based on interference of magnetic, so once these fluctuations exist constantly, it won't cause errors on the measurement. While there are no instruments available to have a test on the actual value of the magnetic, the real affections on are unknown. But it can be still tested on the result of the applications directly.

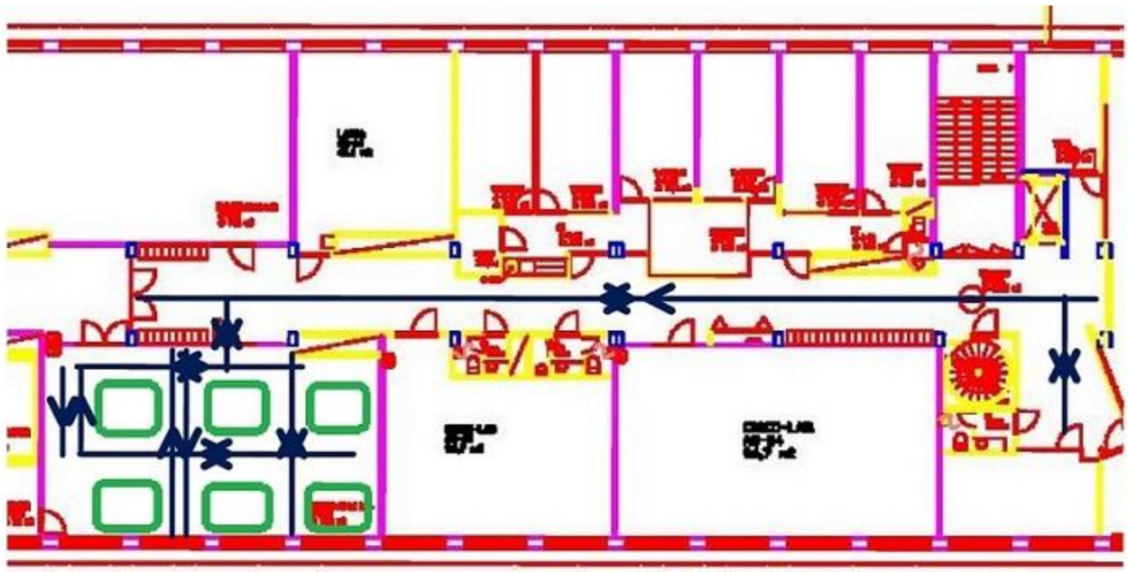

FIGURE 5. Paths made for the map created for the third floor of building A in TAMK

The process of mapping is critical since it can significantly take some effects or even cause errors on the results of the positioning. Here are some crucial rules that have to be followed when making the magnetic map (Elina 2015a).

1. The mobile device used to map must be kept straight ahead in front of the holder directed along the marked path of the drawn lines and aligned with it which is used to place the recorded data on a sensor map of magnetic, trying to avoid waving and shaking which might cause errors. (Elina 2015a.) Figure 6 illustrates the details of the direction of the mobile device and how is the marked path like.

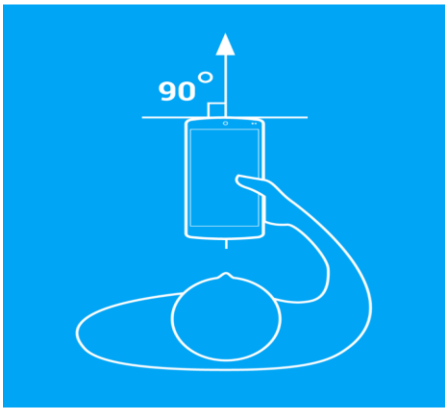

FIGURE 6. Map creating for the third floor of building A in TAMK. (Elina 2015a)

2. When making the records, start walking right away without any hesitating once record button in the MapCreator application has been pressed. The same requirement applies for the end of the path: press stop immediately. Moreover, not to divert from the intended path is another requirement. Otherwise, it will cause any misplacement of the measured data and lead to positioning inaccuracy for the final map. (Elina 2015a.)

In some projects (Haverinen & Kemppainen 2011; Makkonen et al. 2014), robotics which can move in a setting speed with stabilization, steadiness, even smoothness, are deployed to make the recording map. Similar projects were also conducted by Jaewoo et al. (2011). Following this way, the best result should be able to promise since speed, direction, waving can be strictly controlled while waving and shaking can be obviously avoided. Though robotics can add significant cost and time. If it is possible to provide as an assistant tool in the real commercial environment with acceptable price, it should be recommended. But in this project with limit funding and time, it is impossible to use robotics for map recording. So walking for recording as described is adopted for the map creating.

3. The final map can contain information of determining walkable areas or obstacles or walls by connecting recorded paths together so that obstacles and walls can be determined. This can be realized by double-tapping the “add path” button in the MapCreator application to place the start marker on top of the end marker of the previous path to add a new rout. However, it should be noticed that any gap between the recording paths should be less than 1.5m, otherwise, it will be considered as an obstacle between the paths. The obstacle means that the area cannot be reached and are not walkable and it will also prevent the positioning dot from moving between the paths. It is also noted that map can be extended by adding multi paths and it becomes more complex and make the positioning

more accurate(Elina, 2015a). In this project, multi paths for the paths have been made. It can be seen from Figure 5.

4. It is recommended, when it is possible, try to keep 1m distance away from walls while walking along a path during recording. This will help the positioning algorithm maintain the positioning dot away from walls for 1 meter. In real environment, it is natural that users as pedestrian will not get too closed to the walls when walking indoors. (Elina 2015a.) For this project, in the third floor of building A in TAMK, the width of the corridor is about 3 meters, so the requirement can be met. But in the room or A3-20, the width of corridor between the tables and the wall inside the room is less than 3 meters, it is impossible to meet this requirement. But it makes the chance to observe whether these tables and computers can have some effects on the accuracy for the measurement.

The mapping given in Figure 5 has real corresponding relationship with the actual size. For instance, by measuring with the tap, the length of the corridor is approximately 35m, the length showing on the map is exactly 35m.

4.2 Software design of the system

The following paragraphs will focus on the software engineering aspect of designing the indoor positioning system.

4.2.1 Brief introduction on Android APP development

There are numerous of materials and documents that introduce on Android operating system and application development. As concerned in this project, combining with API provided by IndoorAtlas, a couple of issues needed to explained and clarified.

From the architecture diagram for Android system, basically, at high level, android system can be divided into five layers from top to bottom (Android Open Source Project. 2015), shown in Figure 7:

1) Application Framework where the applications lie in (Android Open Source Project 2015).

2) Binder IPC (Inter-Process Communication) proxies which allows the upper layer of application framework to cross process boundaries and call into the lower layer of Android system services code (Android Open Source Project 2015)

3) Android System Services including two group of services: media server and system server. (Android Open Source Project. 2015)

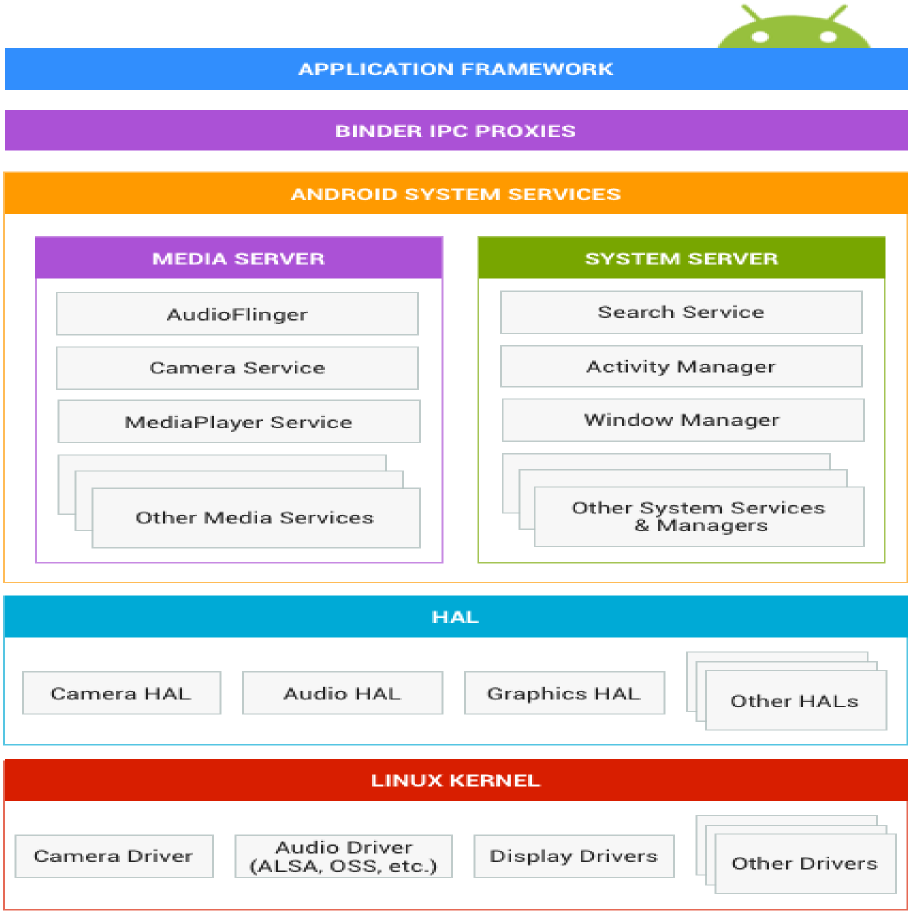

FIGURE 7. Architecture diagram for Android system. (Android Open Source Project 2015.)

4) Hardware Abstraction Layer which defines a standard interface for hardware vendors to implement and allows Android to be agnostic about lower-level driver implementations. (Android Open Source Project. 2015)

5) The lowest layer Linux Kernel (Android Open Source Project. 2015).

In terms of the application of this project, since it has to deal with the data attained from sensors, first top three layers will be covered by the application. And the position of the application in the Android system can be modified and updated to the architecture illustrated in Figure 8.

The application will invoke the methods, interfaces and listeners provided by IndoorAtlas API. So the main task of the application will be user interface design and handlers for the corresponding events monitoring. Detail of the package com.indooratlas.android will be given in the following section 4.2.3.

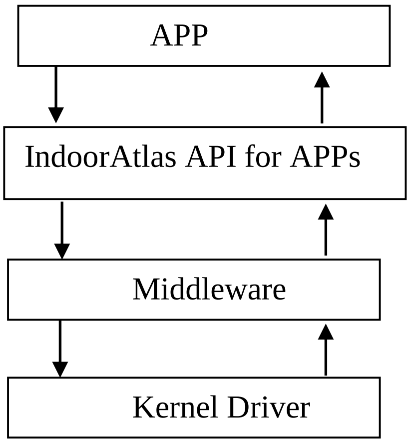

FIGURE 8. Position of application developed in Android system. (Android Open Source Project. 2015)

4.2.2 UI design for the APP

Before the real user interface design on Android system, a mock up is made for the sake of separating the task of designing and programming. In addition, since the mock up design is not specific for certain operating systems for example Android or iOS, both Android and iOS can then later apply for the mock up for the UI design for the system.

The mock up for the application is conducted on FluidUI.com which provides 8 screens with basic elements for the UI design user for the free trial version. Although there are only 8 screens, these 8 UI screens have included almost all the activities needed in the actual user interface. And the screens of the mock up is basically the same as what can be seen in the real application although there will be some differences existing. Appendix 1 shows several of the screens captured.

When starting the program, first screen comes out for initializing programming and welcome information. Then the app enters into the main page. There are four options for selecting when you are at main page: Select the existing map stored to get your position, search the maps by city, browse the maps by country and add nearby maps. Searching or browsing maps is to search the maps you are interested in and then stored on the server.

On the basic version, you could only get limited maps for location. Getting the maps can be realized by connecting the cloud server of IndoorAtlas. Because of the limitation on free trial version from Fluidui.com, not all the activities are made in this mock up. Navigation map for this application is shown in figure 9. And task flow diagram for the application in mock up is shown in Figure 10. It can be clearly seen how the task flow of the application goes.

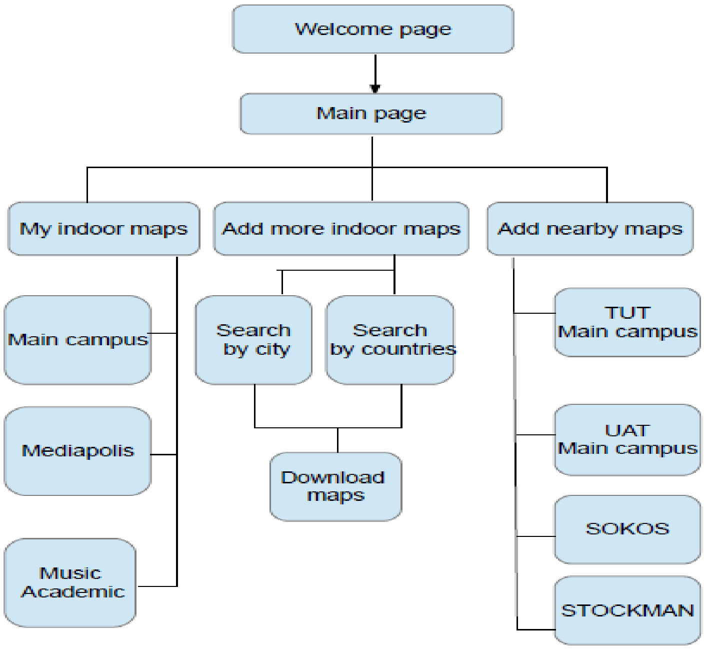

FIGURE 9. Navigation map for the application in mock up.

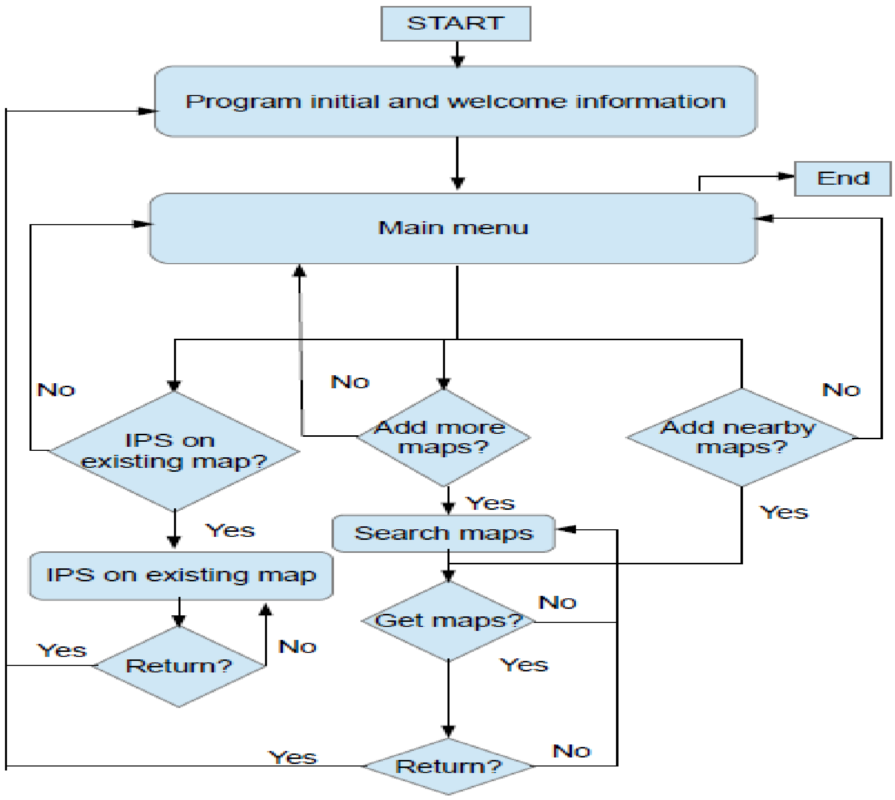

FIGURE 10. Task flow diagram for the application in mock up.

Through the mock up project, basic functions and tasks of the application have been formed during the initial design. Though it is just a concept design but rather in the real design environment, it provides a quick way to come out with the mode of the application and make the real design follow a direction which is set by the mock up project. It will be seen that there will be some differences between the mock up and real application, but the frame and most of the screens of the real application are similar. Actually the real application follows the design from mock up project. The detail design on application on android platform will be shown in the following sections.

4.2.3 Architecture and structure of the application

The package layer of the application can be seen in Figure 11. It is typical structure in Android Studio. It includes the gen package which contains the configuration files automatically generated by IDEA, Java class files, res directory which stores the photos used in UI interface like tamklogo.png, xml layout files for the design files of UI, AndroidManifest.xml which is for the configuration of the project and other resources file created by the Android Studio automatically.

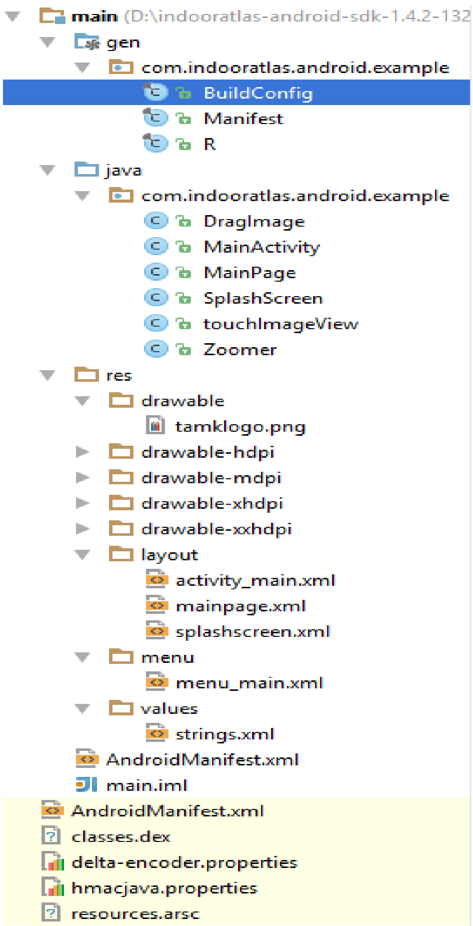

FIGURE 11. Package layer of the application

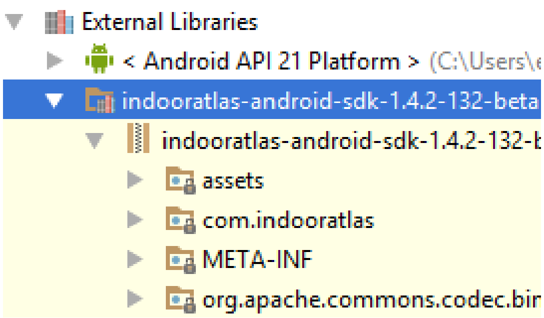

FIGURE 12. Package layer of the application for the libraries

Figure 12 shows the library package includes the basic library from Android API 21 platform and the library from IndoorAtlas. These two libraries provide all the needed Java class and interface for the program.

The MainActivity class is the main java class which implement the functions of loading the floor plan, showing it and location information. So it is the core in the application. It is a sub class of activity so it extends class of activity and implements IndoorAtlaslistener interface which is provided by IndoorAtlas. Table 6 shows the interfaces, classes, Enums and exception used in MainActivity.

Other two important classes in the application are MainPage and SplashScreen for controlling the layout sources files of mainpage.xml and splashscreen.xml correspondingly. Class touchImageView is the sub-class created for displaying the map photo for the loor plan. With touchImageView, map picture then can be zoom in and zoom out in certain scale.

The flow chart for the Class MainActivity which is the core part of the application is shown in Figure 13. First, entry point for every application is the constructor onCreate(BusavedInstanceState) of class MainActivity which is derived from parent class Activity. Then it loads the layout xml file activity_main which is the corresponding layout file of class MainActivity. After that, it initializes the IndoorAtlas listener and obtain instance for positioning service with API key and API secret code assigned from IndoorAtlas when registering. Then loads the floor plan with venue Id, floor Id and floor plan Id and show the map on the UI view class touchImageView. The next step is to judge the flag of mIsPositioning. If it is false, it will stop the program. If it is true, it just starts connecting the cloud server from IndoorAtlas and begins to provide position information in the form of values of x and y pixel on the floor plan. The program will keep on displaying the log information, updating the service and monitoring the variations of the positioning obtained from cloud server.

TABLE 6. Summary for the IndoorAtlas API. (IndoorAtlas Ltd. API. 2015.)

Interface Summary:	Description
CalibrationState	CalibrationState interface provides access to a status event conveying momentary state of the calibration.
FutureResult<R>	Result of asynchronous computation.
GeoPoint	GeoPoint interface provides the position estimate in the WGS 84 coordinate system.
ImagePoint	ImagePoint interface provides the position estimate in the coordinate system of the image that was used in mapping.
IndoorAtlas	Main entry point for interacting with IndoorAtlas positioning services.
IndoorAtlasListener	IndoorAtlasListener is the public callback interface of IndoorAtlas API.
MetricPoint	MetricPoint interface provides x and y coordinates of the position estimate in meters.
ProgressCallback	
ResultCallback<R>	
ServiceState	ServiceState encapsulates the response from IndoorAtlas.
Class Summary:	
ErrorCodes	ErrorCodes class contains the error codes used in service failures.
FloorPlan	Represents floor plan data received from server.
IndoorAtlasFactory	
PositionerParameters	PositionerParameters is a class for passing positioning parameters to IndoorAtlas.
Enum Summary:	
CalibrationEvent	CalibrationEvent specifies the types of calibration events.
Exception Summary:	
IndoorAtlasException	IndoorAtlasException wraps exceptions thrown by the IndoorAtlas API.

The exit point of the positioning service is not given in the class MainActivity directly, but by start/stop positioning item set in the menu which invokes toggle_positioning method to flip the mIsPositioning flag. And then listener in MainActivity judges the flag again to decide whether to start positioning or stop positioning.

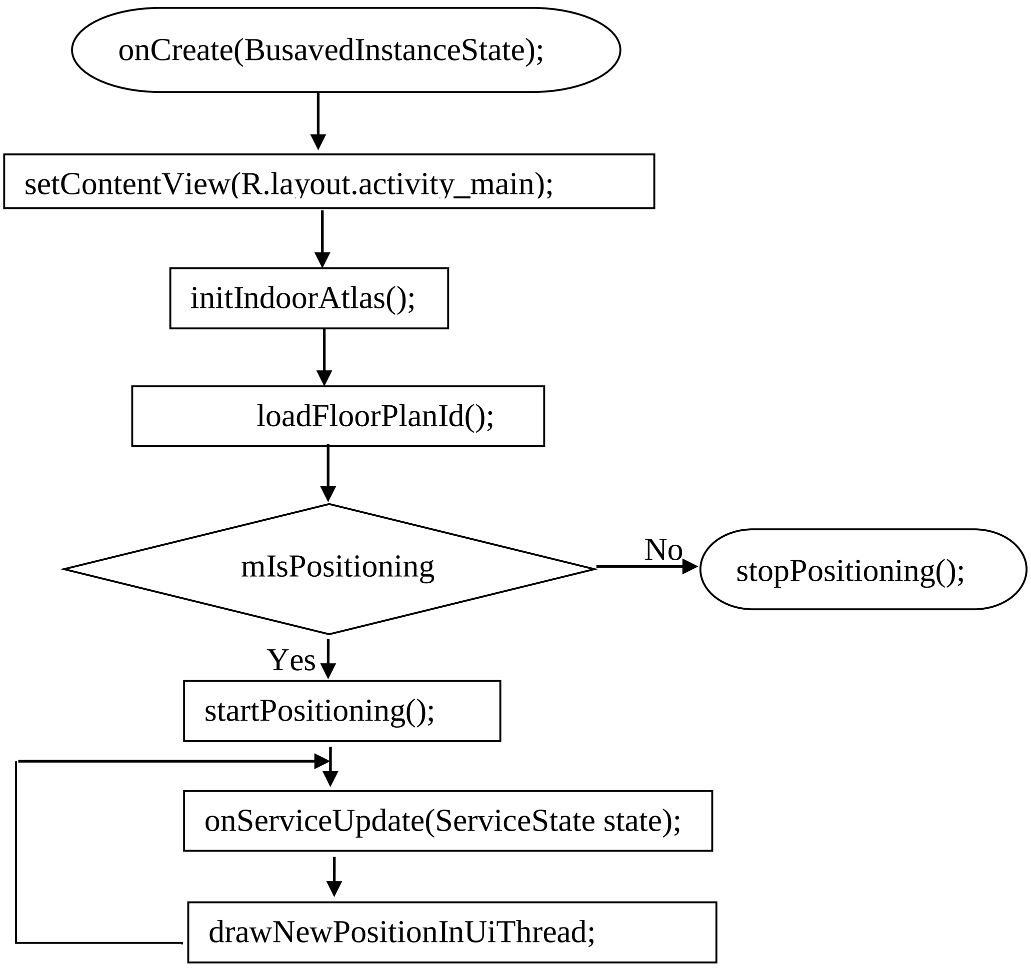

FIGURE 13. Flow chart for the Class MainActivity

4.3 Actual view on the application on Android

Screenshots for the actual application on the smart phones are displayed in appendix 3. Obviously, it can be seen that there are differences between the mock up and actual design. The colour differences are inevitable since it needs to be adjusted according to the real situation. But indeed, basic colours are primarily coincide.

Besides, in actual design, on the main page, there are no search function of map since this function relies on the more maps available on the cloud server. Creating more maps needs the permissions from the owner of the properties. Therefore, in this trial version, this function is cancelled. While message showing 'Ready for positioning' for attention will be shown at the bottom of the application when everything is ready.

Comparing to the mock up, on the map of location, in actual design, map occupies only the upper section of the screen but rather most area of the screen. And half of the space of the screen is given to the log message of the status of running the program. In map page, there is also a menu added for the user to choose the 'Start/stop positioning', 'Clear' and 'Back to Main Menu' instead of the only back button in mock up.

4.4 Evaluation and performance of the system

4.4.1 Evaluation standard

The standard of performance and evaluation for the indoor position system which can be used to compare among different systems has not been found yet.

Unlike the systems developed and experiments done in the articles of Ilari et al. (2010) and Jaewoo et al. (2011) which gather the fingerprints by fix data points or particles and then compare them with the measuring points to get the errors. As indicated in the previous section, the fingerprints of the system developed in this thesis were attained by setting up the floor plan with certain lines in certain speed. Therefore, measurement result cannot be given in the form of those given in articles of Jaewoo et al. (2011) and Ilari et al. (2010) that gave the errors for every data points or particles (Ilari et al. 2010; Jaewoo et al. 2011). However, the measurement result can be given like the form of Makkonen et al. (2014), although it gives the result of its test environment is in the tunnel with x, y in meters in the upper corner of the map. So the measurement method can be also referred to Makkonen et al. (2014) which is also a system developed on mobile device and measures positioning error on the central of the mapping line. Combining the quality report given by IndoorAtlas Maps at their website, the performance of the system can be evaluated and known to be presented (Elina 2015b).

4.4.2 Performance of the system

From visual inspection, the result of testing for the system of positioning in building A3 in TAMK campus is deemed to be satisfactory. Just like the outdoor positioning system, the blue dot showing the position on the map of the mobile device will follow the position where the user stand on. The blue dot will move following the variations of the user's position though sometime its moving is not smooth enough and at some position it will flip away.

Figure 14 gives the quality report for 3th floor in building in TAMK from IndoorAtalas. The area in blue stands for the map area. The colours in green, yellow stand for the positioning performance along test paths. According to the instructions in the report (Elina 2015b), what error means is the mean positioning error in validated map area. The conclusion from this analytics report from IndoorAtlas is: mean positioning error is 1.3m.

TAMK A3 with tables
Mapped area 90.8m²
Validated map area 98.9%
Mapping efficiency 105.2m²/h
Total mapping time 51 minutes
Mean positioning error 1.3m

FIGURE 14. Quality report for A3 mapped floor plan

By inspection, there are actually some positions with larger errors exceeding 5 m where the blue dot flips away from the actual points. But after stepping forwards or backwards a few steps, it will adjust the location to make the blue dot back to the right positions.

Such kind of flip might cause by the process of searching, computing and calibrating from the system. Whatsoever, it will come back to the right rail.

Actual measurement is conducted with a 10-meter measuring tape. 21 points from the mapping area are selected evenly to measure the error of actual positioning and the one shown on the app. It is found that for the same measuring point, the errors are not constant and they would change when walking back and forth, round and round. Particularly, this phenomena happens in the room A3-20 with tables. But when great bias produces, walking around and then back can normally eliminate the initial bias. It should be the result of calibration from the cloud server of IndoorAtalas. Basically, the criteria of measuring the error of actual points with showing points are:

1) If the showing point flips away or is with huge error, walk back and forth, round and round until it comes closer to the actual point.
2) The showing point stay still and stable at least 3 seconds.
3) Points at some crossing and objects like doors and vertical walls are referenced.

Figure 15 shows the actual points from A to V. In the figure, A’ to V’ are the showing points in the app. The sequence of the letters reflect the measurement sequence.

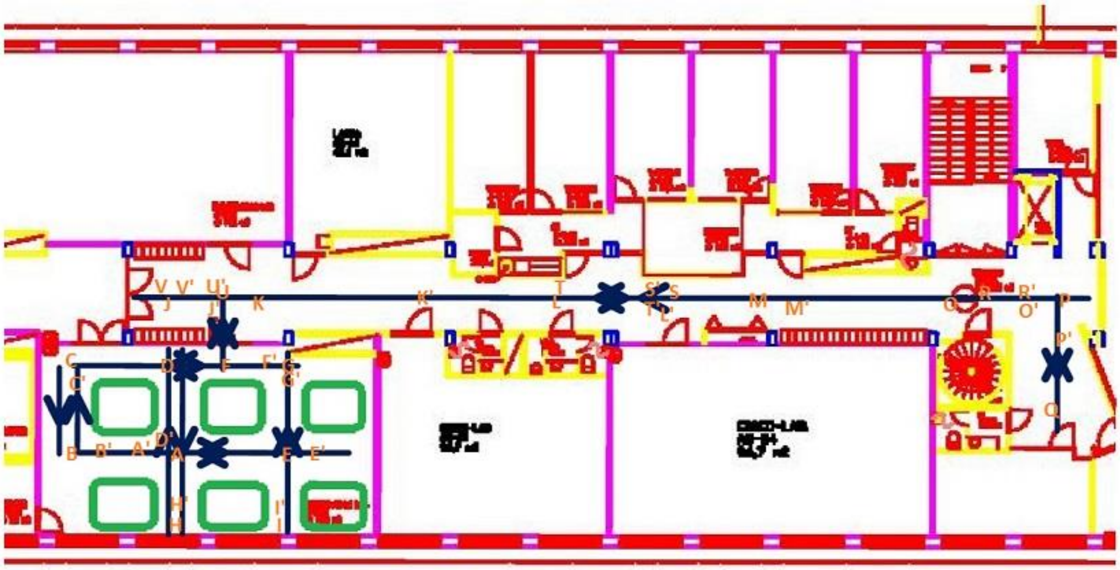

FIGURE 15. Illustration of actual points and showing points

Table 6 gives the measurement result of errors between actual points and showing points. And the mean error for all the measurement points is 1.72m. The value of mean error is a bit larger than the one given by the quality report from IndoorAtalas. With increasing number of the measurement sampling points, the difference should be much less. How ever, K point in Table 6 has significant large error of 5.1m which does not show in Figure 15 with light green error.

TABLE 6. Error for the measurement points and the calculated mean error

points	A	B	C	D	E	F	G
errors(m)	1.8	1.6	1.5	2.6	1.5	2.5	0.3
points	H	I	J	K	L	M	O
errors(m)	0.2	0.5	1.9	5.1	3.2	1.3	3.1
points	P	Q	R	S	T	U	V
errors(m)	2.1	0.6	1.2	0.6	2.9	0.3	1.3
mean error (m)	Sum of the errors/number of points: 36.1/21=1.72						

4.5 Conclusion for this chapter

This chapter describes the design of the indoor geomagnetic positioning system based on the API from IndoorAtlas. The running and development environment or other elements of the design are given in detail. All the aspects of program development of application in Android system platform are introduced steps by steps. At last, performance and evaluation of the system are also shown, results indicates that the system can work properly in the test environment of building A3 in TAMK campus. The errors for the positioning should be acceptable.

5 CONCLUSION

The main objectives of this thesis are: investigate and research the theory and application of different types of existing indoor positioning systems and choose the remarkable solution that is geomagnetic technology to develop a geomagnetic based indoor positioning system on Android mobile device using IndoorAtlas technology.

In the investigate and research stage of this thesis, major existing solutions for indoor positioning systems currently, including WLAN/WiFi and Bluetooth which are the hottest and most attractive technologies in commercial applications, are analysed and investigated. Summaries of merits and weakness for these solutions are presented. Geomagnetic location are studied as well. By comparisons, conclusion can be made that geomagnetic indoor localization is considered to be the most prospective solutions which do not need infrastructures investments, easy to use and with relatively high accuracy.

In the application development section, every aspects of the development project which realizes the location function in third floor of building A in TAMK campus are demonstrated and procedures for development of the software system are introduced step by step, including the UI design, architecture and structure of the program of the application on Android system. Performance and evaluation for the application are presented which shows that the usability and the accuracy of the application can be accepted.

6 SUGGESTIONS AND FUTURE WORK

There are still numerous theory research work and application development work needed to be done in the area of indoor positioning system. As well as those works, the improvement for the application on the Android devices based on IndoorAtlas technology are also needed to be done.

6.1 Suggestions on the theory of indoor positioning

Although a great number of researcher have contributed to work on this area and published large amount of papers on this area, especially on the research of WLAN/WiFi and Bluetooth solution, the research results for the indoor positioning might not be perfect since it can still make some progress on the aspects such as algorithm for fingerprint match improvement so as to meet the computing requirement in real application.

Another possibility is to combine the technology in WLAN/WiFi and/or Bluetooth technology along with geomagnetic solution, which is claimed by IndoorAtlas. Simply added with or combined with another technologies seem not so difficult, while deciding which technology works more precisely in real time and compensation strategy are even tougher. The strategy of embedding and optimizing the embedded those technologies is also the point which needs to be studied. In sum, the future work for theory and research can follow the direction as suggested above.

6.2 Improvement on the application developed in this thesis

Since the limitation on time and resource, the application developed for this thesis has just realized the basic function of indoor position and it is still far from perfect to be commercialized as a product as well. It is obvious that there are still a lot of work needed to be done to improve.

6.2.1 UI design improvement

For an APP running on mobile device, user experience is most vital element to make the application best sell and success in commercial. The application developed in the thesis though provides a user-friendly interface, it still needs to improve. For example, the graphic and colour design can be modified to make it look more professional. The map should be able to be moved on the screen with the finger on touch arbitrarily. The logs printed on the screen can be stored and read at back stage but rather shown in main page in real time. It can only be seen when commands are set.

6.2.2 Usability improvement

Limitation on the API provided by IndoorAtlas which has not yet develop the function of switching the floors automatically, the application developed in the thesis does not own this feature as well. It should take a side effect on the user experience. It can be easily imagined that user might lose great interest and tired of switching the floors. However, this function has to be waited until newer version of API which might provide the interface for switching the floor.

Another usability improvement needed to be done might be adding the tracking and navigate function so that the scenarios proposed in the previous chapter can be realized and the application can become a commercial product at last.

More maps and search function of maps should also be added so as to increase the user experience for the application though it needs more time and efforts. However, unlike outdoor environment where can be reached in most cases, indoor maps are not available in large scope since it needs the permissions from owners of the properties.

6.2.3 Accuracy improvement

Accuracy might be the most valuable characteristic for evaluating the indoor positioning system. In the application presented in this thesis, the accuracy cannot be reached the extent or level which claimed by IndoorAtlas that is 1 m. The errors might be caused by the reasons of mapping procedures or the test devices used on the project or other unknown factors. Further analysis needed to be performed to improve.

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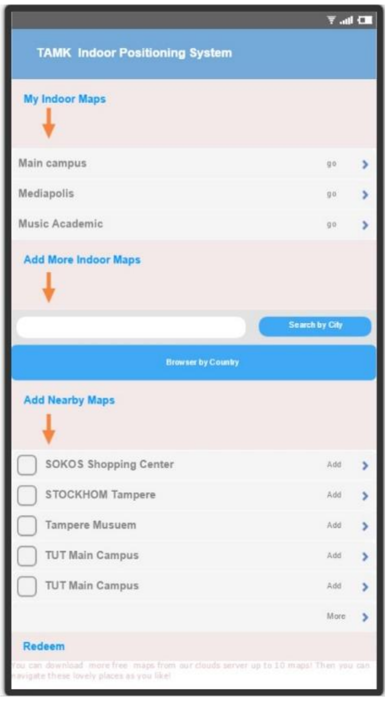
APPENDICES

Appendix 1. Mock up for the application developed in Android system

Appendices are numbered consecutively in the order they are referred to in the text. The appendices must have a title and reference if not constructed by the author.

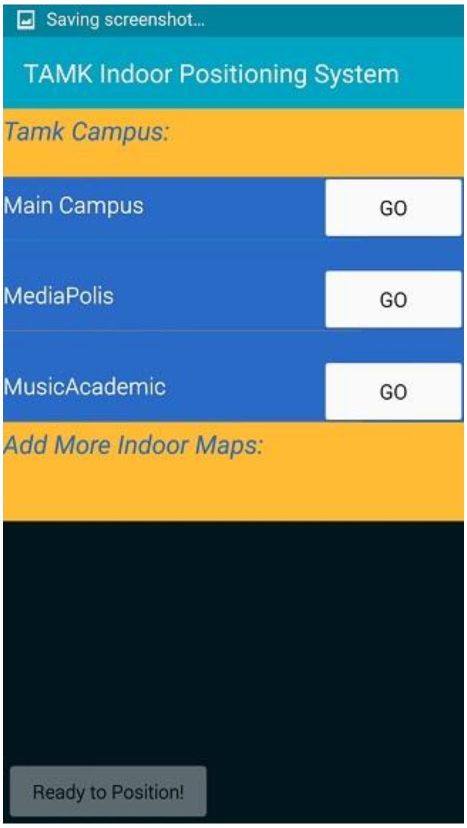


Appendix 2. Pictures for the actual environment in third floor of building A in TAMK

Appendix 3. Screenshots from the actual application on mobile phone

Splash welcome page:

Main menu:



Floor plan loaded:

Running positioning

With menu when running: