An Indoor Navigation System Using a Sensor Fusion Scheme on Android Platform

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AN INDOOR NAVIGATION SYSTEM USING A SENSOR FUSION SCHEME ON ANDROID PLATFORM

by
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ABSTRACT

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With the development of wireless communication networks, smart phones have become a necessity for people's daily lives, and they meet not only the needs of basic functions for users such as sending a message or making a phone call, but also the users' demands for entertainment, surfing the Internet and socializing. Navigation functions have been commonly utilized, however the navigation function is often based on GPS (Global Positioning System) in outdoor environments, whereas a number of applications need to navigate indoors.

This paper presents a system to achieve high accurate indoor navigation based on Android platform. To do this, we design a sensor fusion scheme for our system. We divide the system into three main modules: distance measurement module, orientation detection module and position update module. We use an efficient way to estimate the stride length and use step sensor to count steps in distance measurement module. For orientation detection module, in order to get the optimal result of orientation, we then introduce Kalman filter to de-noise the data collected from different sensors. In the last module, we combine the data from the previous modules and calculate the current location. Results of experiments show that our system works well and has high accuracy in indoor situations.

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TABLE OF CONTENTSs

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Smartphone navigation has become an indispensable function in people's lives [1]. Smartphone navigation makes it possible for applications to track a user's location and direction in real time. For example, when a customer looks up a restaurant on Yelp, they can easily to find the right way to their destination.

While most navigation techniques in smartphone applications are GPS-based, their accuracy become unpredictable in indoor situations due to sensitivity to environmental conditions. For example, when people use a smartphone indoors, the phone usually unable to receive the GPS signal, or the GPS signal may be too weak to carry out an accurate navigation.

With the improvement of the level of hardware, various sensors have been added into smartphones, like gyroscopes, accelerometers, and magnetometers [1], which can provide the necessary data for indoor navigation.

The prospects for indoor navigation are promising. It can be used for public safety measures, and for emergency response. For example, under emergency circumstances such as a building fire, rescue workers could find victims quickly. It also can be used for smartphone shopping, online business, customized advertisement and discount information. In-store customers would have an access to detailed information about where shops are located rather than waste time wandering around trying to finding them.

The goal of this research is to develop a system in smartphone that can navigate in indoor situations. More specifically, we use sensor fusion scheme to build a system because GPS doesn't work for indoor navigation, and sensor fusion can achieve more accurate navigation than with a single sensor. Our work mainly focuses on how to deal with different senor data and combine them to provide the position in real time.

There are two main challenges in developing an indoor navigation system with smartphones. First, the accuracy of sensors in a smartphone are lower than in professional sensors, so it is hard to achieve high accuracy navigation by using a smartphone. Second, we use gyroscope, accelerometer and magnetometer together to determine orientation. The problem with the gyroscope by itself is that it drifts over time, which means the error of the results from gyroscope will increase over time [2]. For accelerometer and magnetometer, they are easily influenced by environmental factors, such as intense magnetic fields around them [3]. In other word that gyroscope can be used on the short term, while accelerometer and magnetometer can be used on the long term. Accordingly, we introduce a filter to balance these two kinds of data.

This thesis provides a detailed introduction to the Smartphone Indoor Navigation System. First, a distance measurement module uses an efficient way to estimate the stride length and uses step sensor to count steps, then calculate the distance that a pedestrian has walked. Second, in order to reduce errors from different sensors, the orientation detection module uses Kalman filter to denoise to get an optimal result of orientation. Finally, we developed a sensor fusion scheme to achieve high accurate indoor navigation with Android platform.

In summary, the contributions of our work include:

1) Navigation algorithm that uses data from sensors to achieve indoor navigation

2) Succssfully reduce the noise of data from different sensors by using Kalman filter

3) Sensor fusion scheme that combines different sensors to improve the accuracy of indoor navigation

4) Low power consumption system that is suitable for Android smartphone

The main contribution of our work is a sensor fusion scheme for indoor navigation system on smartphone. In particular, our model combines the data from various sensors and implements algorithms to de-noise the data to achieve high accurate indoor navigation with smartphones. Our system also achieves low power consumption by using step sensor instead of other sensors.

CHAPTER 2: BACKGROUND

2.1 Sensors in Smartphones

Due to rapidly advancing technology, sensors have become more common in smartphones compared to earlier versions. These sensors include light sensors, orientation sensors, proximity sensors, sound sensors, and pressure sensors, etc. Among them, accelerometer, gyroscope, and magnetic sensors are mainly used in the indoor navigation system.

Accelerator is a Micro-electro-mechanical system (MEMS). As its name reveals, the acceleration sensor can measure the acceleration of the phone [3]. When the mobile phone is moving, the acceleration sensor returns a signal output; when the phone is stationary, the acceleration sensor returns no signal output. The acceleration sensor also measures the angle of the handset in three directions.

The gyroscope provides more accurate angle information. With the gyroscope, Android's Photo Sphere camera can determine in which direction the phone is rotating and the number of degrees [2]. Google's Sky Map uses the gyroscope to determine which constellation the phone points to.

Another sensor applied in the system is a magnetic sensor that can detect magnetic fields [4]. Magnetic sensors are one of the sensors used to determine the Earth's Arctic. Applications can also use magnetic sensors to detect metal materials and determine the magnetic changes around the phone.

2.2 Android Operating System

2.2.1 Introduction

Android is an operating system based on the Linux kernel [5]. It was developed by the Open Handset Alliance (OHA, Open Mobile Alliance), which was founded by Google. The system is designed primarily for touch-screen mobile devices.

2.2.2 Features

Display: Android supports great resolution. VGA, 2D display, and 3D display are given OpenGL ES 3.0 standard specifications. Version 4.3 began to support OpenGL ES 3.0. It also supports the traditional smartphone [5].

Information: The Android operating system supports SMS and e-mail, all the cloud information, and server information.

Browser: Android operating system has a built-in web browser based on WebKit core, and uses the Chrome V8 engine.

Support for Java: While most of the apps in the Android are written in Java. Since Android does not come with a Java virtual machine, you cannot execute Java programs directly. But, the Android platform provides a number of Java virtual machines for users to download. After the installation of the Java virtual machine, Android system can execute Java_ME program [5].

Wireless sharing function: Android operating system allows users to use the machine as a "wireless router," and the machine's network share to other smart phones; other machines only need to find a shared wireless hotspot Wi-Fi, and they can access the Internet. Versions of Android 2.2 and earlier will need to use third-party applications or other customized versions of the system to achieve this function.

2.2.3 Platform Architecture Structure

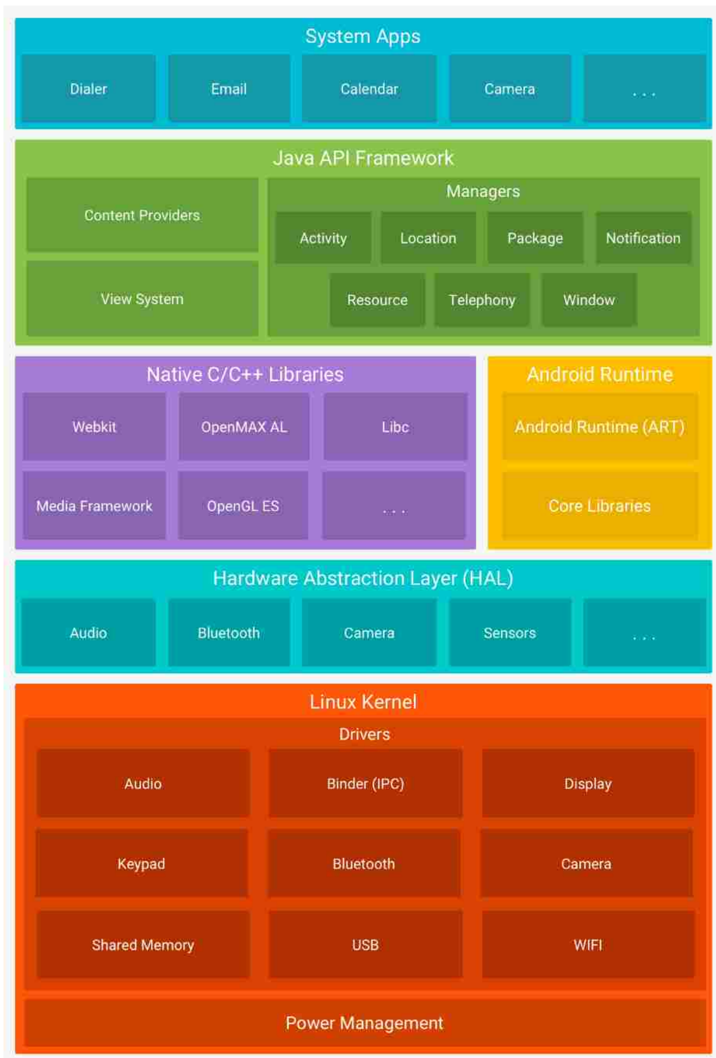


Figure 2.1: The Android Software

Figure 2.1 shows the whole architecture and each component of the Android platform [6].

The Linux Kernel: The Linux Kernel is Android's core system services. It also plays a role as an abstraction layer between the hardware and the software stack [6].

Hardware Abstraction Layer (HAL): Android hardware abstraction layer, in simple terms, is the Linux kernel driver package, providing the interface for the upper layer, shielding the implementation of low-level details. In other words, the hardware support is divided into two layers, one on the user space and another one on the kernel space. The reason for doing so is to follow GNU License.

Android Runtime: Android Runtime (ART), is an operating system environment running on Android, developed by Google in 2013 as a test function in the Android 4.4 system. ART was officially released in Android 5.0 and subsequent Android version. As a formal runtime library, it replaced the previous Dalvik virtual machine. ART can convert the application's bytecode into machine code, which is a new virtual machine used by Android. The main difference between Dalvik and ART is that Dalvik uses JIT technology, while ART uses Ahead-of-time (AOT) technology. ART also improves on performance, garbage collection, application debugging, and performance analysis.

Native C/C++ Libraries: Android includes some C / C ++ libraries. Developer can get services from them through the Android application framework. The core libraries mainly include the basic C library, multimedia libraries to support a variety of multimedia formats, bitmaps and vector fonts, 2D and 3D graphics engine, browser, database support [6].

Java API Framework: Android applications are written by using Java. The program runs in the Android runtime. The runtime includes two parts: core library and Dalvik virtual machine.

System Apps: Android not only contains the operating system, but also includes many applications. Developer can use their own application to replace these system application. This makes Android become more flexible and personalized than other mobile system.

2.2.4 App Components

Intent: Strictly speaking, Intent is not a component of Android applications, but it is very important for the role of Android applications, serving within the different components as the carrier between communications. When the Android runtime needs to connect different components, Intent is needed. Intent is the carrier of the communication between the three components, Activity, Service, and BroadcastReceiver, but different components use the Intent mechanism in slightly different ways.

Activity: An activity usually means a screen in an application. It can handle the user's event and respond. Activity communicates through Intent. In the description structure of Intent, there are two important parts: action, and the data corresponding to the action. Typical action types are: MAIN, VIEW, PICK, EDIT and so on. The data corresponding to the action is expressed in the form of a URI. For example, to see a person's contact, you need to create an Intent with an action type of VIEW and a URI that represents the person.

Activity provides a visual user interface for Android applications, which can be understood as a basic component. If the Android application requires multiple user interfaces, then the Activity application will contain multiple activities. Through these programs, multiple interface display and event handling can be completed.

Service: The status of Service and Activity are parallel. Service also represents a separate Android component. Service usually runs in the background. It generally does not need to interact with the users, so Service components do not have graphical interfaces. Service component needs to inherit the Service base class. A Service component will have its own lifecycle after it runs.

Content providers: For Android applications, they must be independent of each other, running in their own Dalvik virtual machine instance. Sometimes, these Android applications need to achieve real-time data exchange. For example, we have developed a program to send text messages. When sending text messages, we need to read from the contact management application to specify the contact data, which requires multiple applications between the real-time data exchange. The Android system provides a standard for this cross-application data exchange in the form of Content providers.

When the users utilize their own Content providers, an application needs to complete the following action using the Content provider: insert the data, delete the data, update and query. Usually, Content resolver is used with Content provider. An application uses Content provider to expose its own data, while another application accesses the data through Content resolver.

Broadcast: BroadcastReceiver stands for broadcast message receiver. An application can use it to filter exterior events and only receive and respond to the events of interest. The broadcast receiver does not have a user interface, but it can respond to the information it receives by starting an activity or service, or use the NotificationManager to notify the user. Notice can be used in a variety of ways to attract the attention of the user, such as flashing back lights, vibration, play sound, and so on. In general, with a persistent icon on the status bar, the user can open it and receive the message [5].

CHAPTER 3: MOTIVATION

To demonstrate our motivation for this research work, we present two simple scenarios to illustrate how our indoor navigation system aims to solve different situations.

3.1 Scenario 1

Amy is a senior student at Marquette University. She needs to go to the career fair, which is held in the Alumni building. She wants to go to the booths for the companies Direct Supply, Harley Davison and Johnson Control. However, there are more than 50 booths from different companies in the career fair. It is hard for Amy to find the booths of the companies she is looking for among so many booths in such a large room. Moreover, she doesn’t know where she is when she walks around. With the indoor navigation app, Amy can accurately get the information about the location of the booths she is looking for and her own location. From this information, she can find the companies’ booths conveniently. The indoor navigation app can also be used when Amy is in a large indoor shopping mall. The app helps Amy find the direction to go to the stores she is interested in.

3.2 Scenario 2

Bill just checked in to a large hotel. There is a fire in the hotel. Since Bob just checked in, he is not familiar with the ways to the exits. Moreover, the smoke of the fire makes the exit hard to find. He can use the indoor navigation system to determine his own location in the building and location of the closest exit. While he is walking in the building, he can tell which direction he is walking in, and how far he is from the exit to get out safely.

3.3 Summary

These two scenarios clearly show that how our indoor navigation system can be used in daily life. We aim to build this system to make people’s lives more convenient and help people deal with emergencies that might happen. Our goal is make the system achieve high accuracy and have low power consumption. The indoor navigation system can be used in a wide variety of scenarios, both in personal life, as well as industry applications and emergency rescue scenarios.

CHAPTER 4: RELATED WORK

4.1 Indoor Positioning Technology

There are many popular existing indoor positioning technologies, classified into multiple types. For example, according to a different algorithms for positioning, they could be classified into technologies 1) based on the Termination, and; 2) based on the server. They could also be categorized into 1) Active positioning Technology, and; 2) Positive positioning Technology. Accordingly, based on in view of the positioning coordinate systems in use, they could be classified into 1) relative positioning technology, and; 2) absolute positioning technology. Lastly, based on the different infrastructure used, they could be classified into 1) Global positioning Technology; 2) Positioning technology based on Short distance wireless communication technology; 3) Positioning technology based on the WIFI, and; 4) Positioning technology based on the inertial sensor.

The technologies mentioned above depend on the strength of different infrastructures or networks. Meanwhile, each of them have advantages and disadvantages on accuracy, spending and valid range. We provide brief introductions of several specific positioning technologies below.

4.1.1 Global Positioning Technology

There are three main parts in GPS: space, console and terminal devices [7]. In space, the satellite will send navigation signal and distance measurement signal to track the terminal device.

Main console, monitor station and ground antenna are the main components of console. They are mainly responsible for tracking, maintaining and detecting the satellite. The terminal devices, named the user devices, are receivers. They are mainly responsible for receiving the signal sent from the satellite to calculate the three-dimensional coordinates, time and speed.

The theory of GPS involves calculating the propagating time of positioning signal from a satellite to the terminal device, time it with light speed, so pseudo distance can be calculated [7]. We could get a group of functions with more than three positioning satellites here. By working out these equations, the time and location of the terminal device could be calculated.

GPS has become one of the most popular technologies with a wide application scope. GPS provides services continuously and with steady deviation, they can be applied in a smart navigation system. However, walking characteristics of humans and movement of vehicles are obviously different, since human movement is more random and complex than with vehicles. For instance, the GPS signal can easily be blocked and attenuated if people go inside, such as to an office, library or museum. Indoor places can have complex environments. Additionally, GPS signal is easily influenced by some other RF signals. All of these factors will lead to poor positioning accuracy. Therefore, other positioning technologies need to be auxiliary in such complex environment.

4.1.2 Positioning Technology Based on Short Distance Wireless Communication

In a complex indoor environment, the other indoor positioning technologies should be used since GPS signal is easily attenuated. Based on the baseband and theory of positioning technologies, it could be classified into 5 different methods.

1) Positioning technology based on ultrasonic: The ultrasonic positioning system is constituted by a major range finder and multiple electronic labels [8]. When the system is working, the range finder sends a signal. After receiving the signal sent from the rangefinder, electronic labels return the same signal to the range finder. The distance can be calculated by this process. However, because of ultrasonic's attenuation when propagating, it can only be used in a specific small area.

2) Positioning technology based on infrared light: Infrared light's wavelength is located between radio wavelength and visible light wavelength [9]. For example, active badges are based on infrared light positioning system. This system will automatically add an electronic label on a target, and the label will periodically launch infrared light. The receiver, which is installed indoors, will receive the signal and transfer the signal to a database via the internet. Then the location can be calculated and obtained [10]. However, infrared light can be blocked by glass, a wall or a chair. Its valid transmission distance would be limited, and the system is also complex.

3) Positioning technology based on ultra-wideband: Ultra-wideband (UWB) positioning technology has several advantages: high transmission speed (maximum 1000Mbps), low power consumption, strong penetration and no carrier [11]. Therefore, it is more accurate than the other technologies mentioned above. The UWB positioning system mainly includes a receiver, reference labels and active labels. The receiver will receive the signal launched by

reference labels when positioning. After that, the receiver will obtain a valid signal and filter the noise. Consequently, the target location could be calculated by TDOA (a method used in UWB positioning technology to calculate the location by valid signal). However, it is not suitable for large scale applications because of its high manufacturing cost [11].

4) Positioning technology based on the RFID method: RFID technology is a kind of easy-to-use automatic identification technology [12]. The standard RFID positioning system includes electronic labels, RF reader&writer and database. The electronic label is put on the target and RF reader&writer is embedded in the working environment. When the RFID system is working, the RF reader&writer is continuously communicating with the electronic label. Then, the electronic label location can be calculated. In order to improve accuracy, many electronic labels are used. However, high-density electronic label application will affect signal propagation and location calculation.

5) Positioning technology based on the ZIGBEE positioning system: The ZigBee positioning system mainly makes use of the distributed wireless sensor network to distribute the reference node and the moving node [13]. According to the static reference network node, it will send Received Signal Strength Indication (RSSI) to the moving node. The moving node will use a classic algorithm, such as weighting algorithm, to obtain its own position. By using the wireless sensor network, the workload of internet transmission could be reduced dramatically and the performance of the signal improved. Even though ZigBee positioning technology has a great accuracy (2m), it is easily influenced by environment, and internet stability also needs to be ensured.

4.1.3 Positioning Technology Based on WIFI

The IEEE802.11b wireless network is widely used nowadays. It has become a popular indoor positioning technology because of its wide covering range and convenient use. People can obtain wireless signals by laptops or mobile devices. Besides, there are many mature indoor positioning algorithms basing on the 802.11 protocol [14]. Most of them analyze and calculate a target's location by RSSI.

The common WIFI indoor positioning algorithms include location fingerprinting method [15], probability distribution method [16] and signal propagation attenuation model [17]. They are based on the classic RSSI indoor positioning algorithm. RADAR positioning system [17] is a successful application of WIFI indoor positioning technology. Location fingerprinting is widely used in the RADAR system, and indoor wireless signal attenuation model is developed from the RADAR system. Location fingerprinting method based on the Probability distribution method is then discovered.

The WIFI indoor positioning technology has many advantages, including wide coverage range, it is suitable for large scale use, and provides higher accuracy (2m~3m) [14]. However, reflection, diffraction, scattering, refringence and other multipath effects will have an influence on the accuracy of positioning. Additionally, power consumption and portability are issues because a large amount of wireless communication data needs to be captured.

4.1.4 Positioning Technology Based on the Inertial Sensor

With the development of MEMS [18], the size of sensors became much smaller and cheaper, so that they could be more easily applied in terminal devices, such as mobile devices. The positioning technology based on the inertial sensor has continuity and autonomy [19]. Acceleration transducer, gyroscope and magnetic compass fall under the category of involved inertial sensors. With different physical features and application environment, these sensors compose different schemes.

Based on inertial sensors, there are two methods. The first one makes use of a traditional inertial sensor for integrating positioning. According to Newton's laws of motion, the speed and location of three orientations can be calculated by the acceleration of three orientations respectively. Theoretically, the result would be precise and reliable. However, the result of the deviation, calculated by Newton's laws of motion, could be hundreds of meters due to the data drift on acceleration transducer. Another method is the trajectory estimation method. This method, based on the inertial sensor, calculates location by bestride length and the number of steps. The result is more accurate than the first method. However, the deviation can increase similarly, since this technology depends on the length and count of human steps.

4.2 Current Existing Problem and Plan for Indoor Positioning

As mentioned above, every indoor positioning technology has its unique charms. However, defects exist. The positioning technology based on GPS has unsatisfactory accuracy because of GPS signal propagation attenuation [7]. Positioning technology based on short distance wireless communication only has a small coverage range. More hardware is required if we want to increase its accuracy. The positioning technology based on WIFI has a larger covered range than short distance wireless communication and a satisfactory accuracy [14]. It is suitable for long term service, and there is no accumulation deviation. However, its accuracy is related to the distribution of established wireless network access points, unrelated external noise and the RSSI database, which dramatically increases the cost and limits the fields of application. The positioning technology based on the inertial sensor is widely used because it just hawar low cost, small size and autonomous positioning. However, it cannot be used for a long time due to the accumulation deviation.

This thesis mainly focuses on the general, broad, continuous, autonomous and high-effective indoor positioning technologies to realize a positioning system with inertial sensor and wireless signal.

The development of the Internet and the Internet of Things (IOT) has brought many changes into our lives. According to a report published by IHS iSuppli [20], the global total smartphone and tablet users will rise to 1.03 billion in 2015. At the end of this year, there will be more than 4 billion smartphone users all over the world, and everyone can access the internet through this "Palm-Sized PC."

Positioning technology based on the inertial sensor has the feature of autonomy and continuity. Because of the small size of the hardware, low cost, unlimited applications and undistributed feature by external signals, it could get a precise result in a short time. But the deviation accumulation has not been solved yet. Positioning technology based on WIFI could be distributed indoor widely, and it is suitable for large-scale positioning. There is no deviation for the absolute positioning by analyzing the data acquired from RSSI of WIFI. In conclusion, this thesis will introduce the combination of the positioning technology based on the inertial sensor and the positioning technology based on WIFI. Our goal using this method is to effectively reduce the deviation accumulation.

CHAPTER 5: SYSTEM DESIGN

In this thesis, we present our application developed on Android platform. There are three main reasons why we chose Android. First, Android system has a large user group, and users can easily to install and operate the software. Second, the sensors we used are all from android smartphone, which have low cost. Moreover, Android system provides various sensors' API for developers to easily employ them.

5.1 Systems Architecture

The whole application is designed following Model–View–Controller (MVC) pattern [21]. These three layers are shown in Figure 5.1.

View: The task of this layer is showing the related information to the user. The information has two main parts. The first one is map information, which includes the indoor map, the point of the user on the map and the path the user walked. The second part is digital information, which includes the total number of steps, the coordinates of the user and the distance the user walked.

Controller: This layer is used for accepting input and converts it to commands for the model or view. In our application, it is used to monitor the sensors and for the communication between activities.

Model: We implement all logical parts in this layer, which includes stride length detection, heading (orientation) detection, Kalman filter and dead reckoning algorithm.

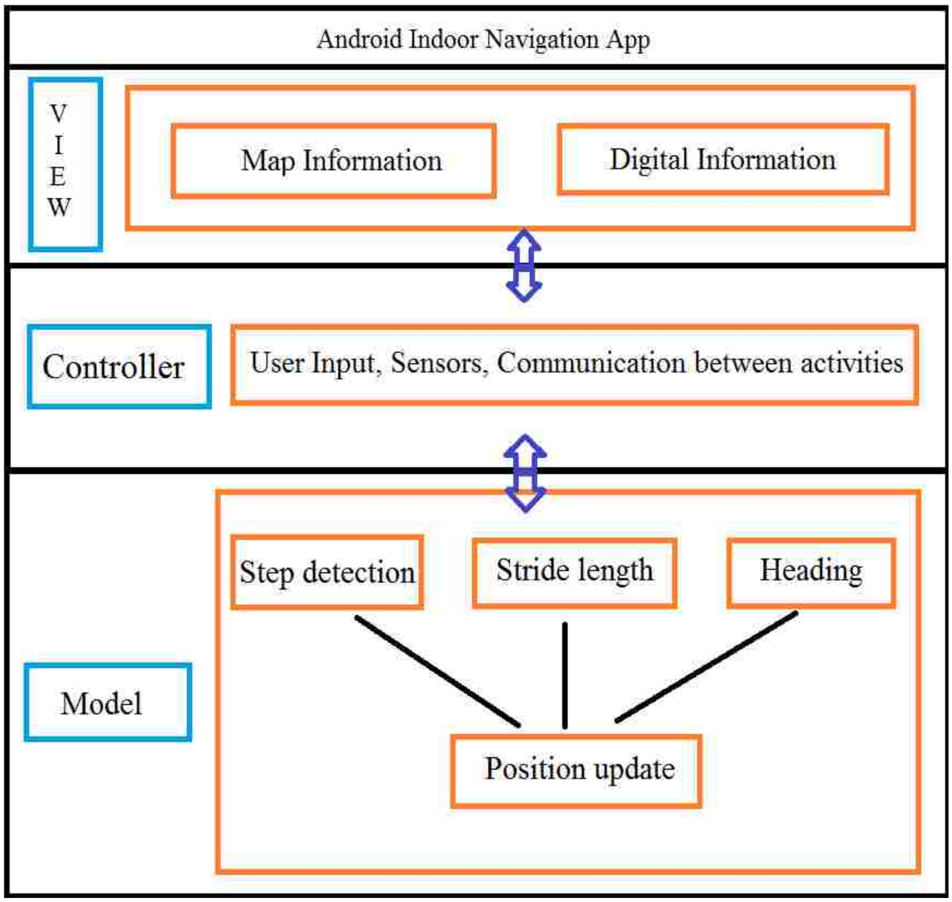


Figure 5.1 System Architecture

The principle of our system to achieve indoor navigation is based on dead reckoning. More specifically, based on the previous position, we use real time data from sensors to update the position in each time interval. For this purpose we need to know the distance that the pedestrian has walked and the orientation of the path.

The process of the system is shown as Figure 5.2.

Step 1. When the system starts

Step 2. Identify whether the GPS is available. If yes, use GPS to navigate. If no, use sensor fusion to navigate.

Step 3. Update the location information on map.

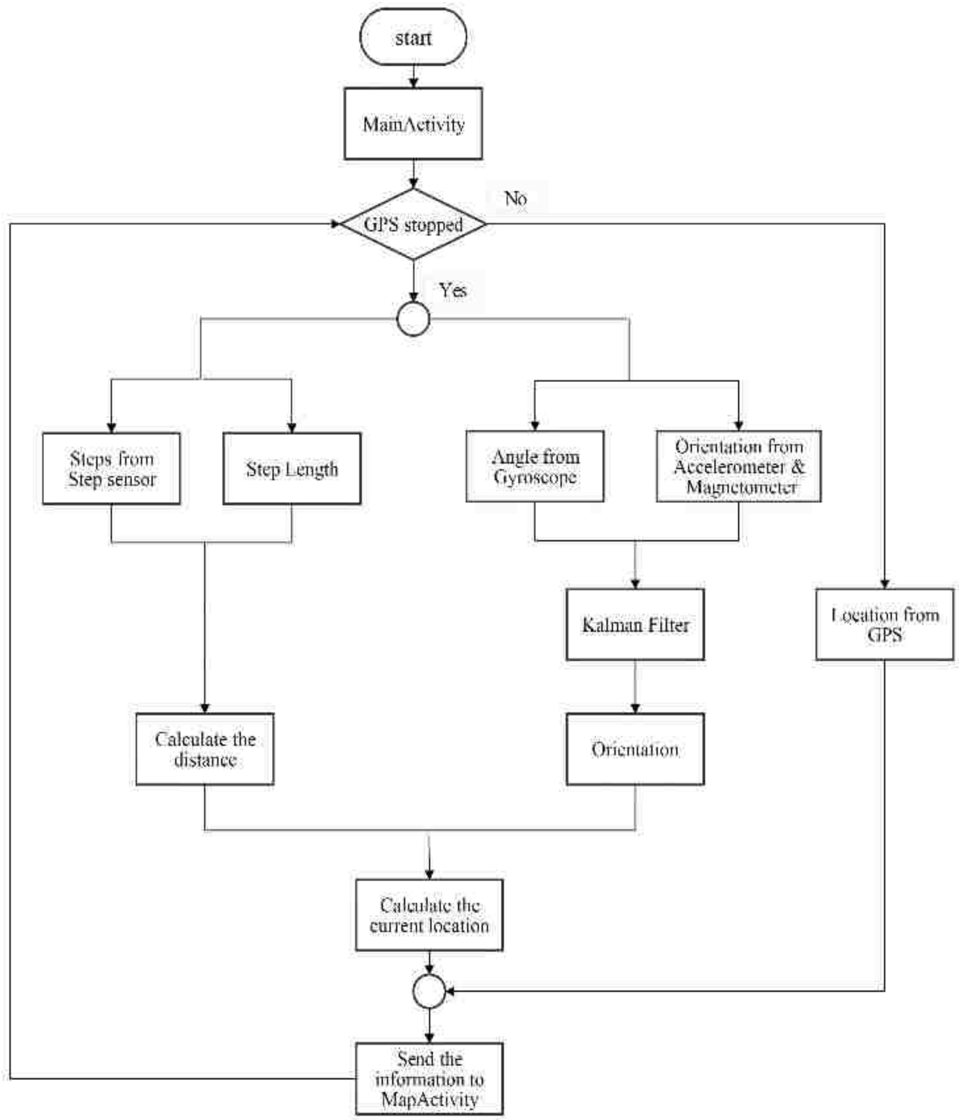


Figure 5.2 Overall System modules and interactions among them

Our sensor fusion scheme has three main parts. The first part is the distance measurement module. The principle of this part uses stride length to multiply steps to get the distance. The second part is the orientation detection module, which calculates the angle difference as the user moves on. The last part is position update module, which combines the data from two previous parts to calculate the current location.

5.2 Distance Measurement Module

In this part, we use step sensor to count steps and use an efficient way to estimate the stride length. Then we calculate the distance that the pedestrian has walked.

5.2.1 Step Detection

To collect the step counts information, we directly use the step sensor to detect steps. This sensor is supported by Android 4.4 KitKat, one of the most accurate pedometers available in a smartphone right now. We can get the steps information from step sensor easily and directly without using other sensors.

The data we get from step sensor is the total amount of steps, starting up when the smartphone boots. So, the number we need is the amount of steps at the current point minus the amount of steps at the last point.

There are two main reasons for using step sensor. First, it is a hardware-based sensor, which means it is accurate. The Android sensor framework has two main types of sensors: hardware-based and software-based [22]. Hardware-based sensors are physical components. They directly measure specific environmental properties and get the data. Software-based sensors are not real sensors. They get data from other hardware-based sensors [22]. In most cases, the accuracy of hardware-based sensors is better than software-based sensors. We believe that the accuracy of the step sensor can be trusted and performed an experiment to verify our belief.

In this experiment, 20 people walked 100 steps with our smartphone, and we collected the data from the step sensor. Figure 5.3 shows that we found the data from step sensor to be close to the actual steps (100 steps). The average of the steps from the sensor is 99.85, which is acceptable.

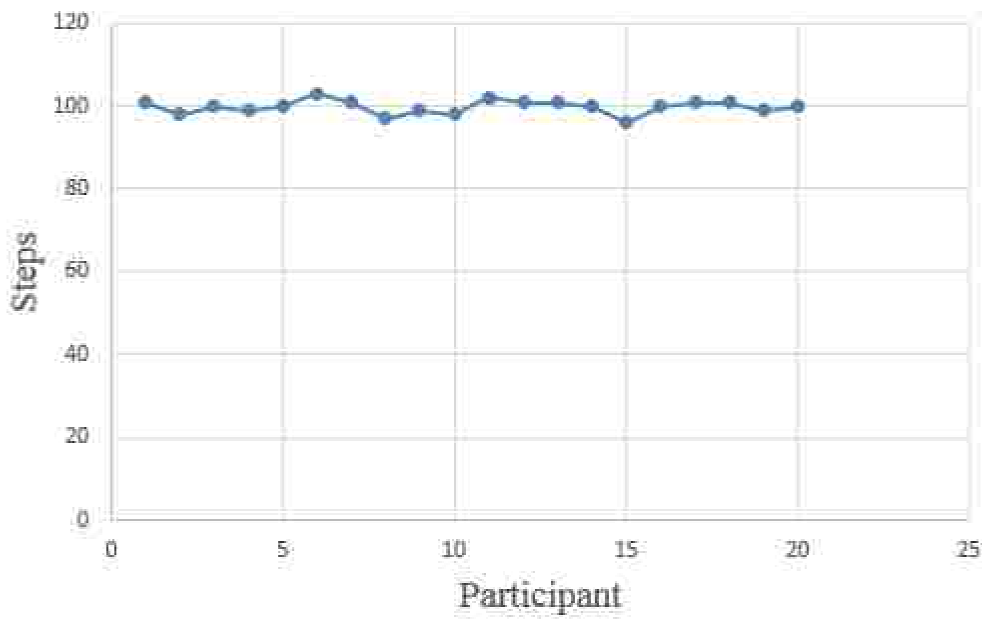


Figure 5.3 Experiment result for step sensor

The second reason we use step sensor is that the step sensor requires less power than other sensors. Since smartphones don't have a specific sensor for step detection, people used to amalgamate different sensors to achieve the goal, meshing gravity sensor data with accelerometer, for instance. This method accelerates the rate of battery drain, as keeping these sensors awake and interpreting the data they spit out requires quite a lot of power. The step sensor knows a step is taken by using accelerometer, then uses the step counter to initiate counting. If the step sensor finds no steps taken, the step counter will not run. In our current implementation, we use step sensor with Android 6.0 system.

5.2.2 Stride Length

Since the stride length will change while walking related to speed, we use acceleration to determine the stride length. In our work, we refer to [23], which shows that "As period of one step becomes shorter, a stride becomes larger, and the vertical impact becomes bigger as the walking speed increases".

The equation represents the relation between measured acceleration and stride.

$$\text{stride(m)} = 0.98 * \sqrt[3]{\frac{\sum_{k=1}^{N} |A_k|}{N}}$$

We perfomed an experiment where the tester walked 150 steps with our smartphone, and we collected stride length for each step. Figure 5.4 shows the test result of the experiment.

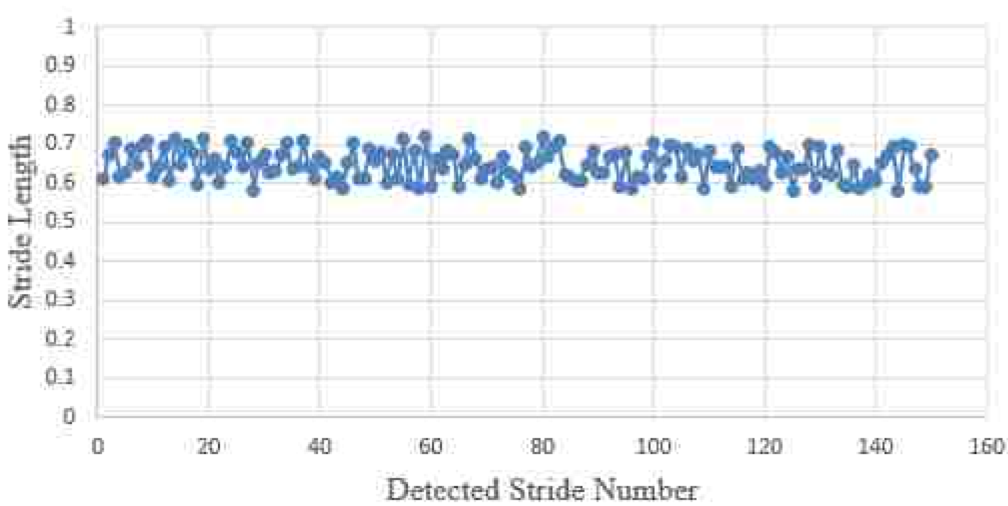


Figure 5.4 Result of stride length experiment

The figure clearly shows that the value of stride length was smooth and reasonable. The total distance collected by using this algorithm was 97.42 m, which is close to the actual distance 102.72 m, and the error for each step is 0.035m. With the results of the experiment, we trust this algorithm and use it to determine the stride length.

5.2.3 Distance Calculation

After collecting the steps and step length, we can easily calculate the distance that the pedestrian has walked in a period of time by following equation:

$$\text{Distance} = \text{steps} \times \text{stride length}$$

We use the low-cost sensor and method for achieving distance measurements so that our system can ensure strong performance on Android smartphones.

5.3 Heading (Orientation) Mode

After calculating the distance, we proceed to find out how a user changes his direction from the previous position. To achieve this, one simple solution is to use accelerometer or gyroscope to get the angular difference; however, this method include unpredictable noise, especially in indoor situations. For example, magnetometer is not sufficient, as it is affected by surrounding magnetic fields.

To solve this problem, we use a sensor fusion scheme to achieve accurate indoor navigation. Here, by sensor fusion, we mean to combine the data from different sensors to calculate the orientation value and filter the noise by using algorithms. To do this, we introduce Kalman filter.

The sensor fusion scheme is shown in Figure 5.5. We get orientation from accelerometer and magnetometer. As the same time, we get rotation angle from gyroscope. Then we use Kalman filter to combine these two data to get an optimal result of orientation.

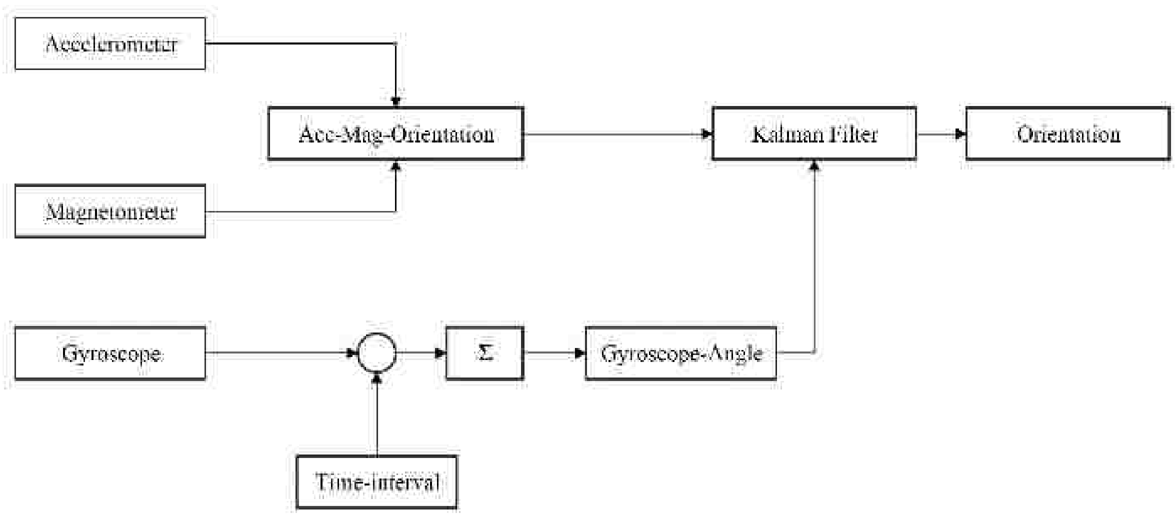


Figure 5.5 Sensor fusion scheme for orientation detection

5.3.1 Gyroscope

We use gyroscope to get the rotation angle in $\triangle t$ time. Gyroscope can be used to measures the rate of rotation around the local X, Y and Z axis of the device. So, after getting the rotation value from gyroscope, we use the following equation to get the corresponding rotation angle during $\triangle t$:

$$\text{rotation angle} = \text{angular speed} \times \triangle t$$

Gyroscope has no external disturbances and it is accurate in short time. The problem is that it drifts over time, which means the errors of the results from gyroscope will increase over time. To solve this problem, we use Kalman filter to remove the drift.

5.3.2 Acc-Mag-Orientation

Using accelerometer and magnetometer is a good way to get orientation over the long term because they have long term stable accuracy. But the problem is that they have unpredictable external disturbances, which means they are unstable in the short term. Since we cannot get an optimal result of orientation by just using gyroscope, we use accelerometer and magnetometer to get additional orientation information as a reference to fix the error of gyroscope.

Android has the getOrientation function to get orientation. The function has two parameters. The first, R, is rotation matrix, and the second value is an array of 3 floats to hold the result. Before we use this function, we need use getRotationMatrix function to get rotation matrix. This function has four parameters: R is rotation matrix, I is the same as R. Gravity and Geomagnetic can be simply obtained from accelerometer and magnetometer. Then, we can get values[0]: Azimuth, angle of rotation about the -z axis, which is the heading when the smartphone is placed horizontally.

5.3.3 Kalman Filter

As stated above, we use Kalman filter to de-noise data and get the final accurate orientation. The Kalman filter can be called an optimal recursive data processing algorithm. It is a way to estimate the optimal system state by using observation value and the previous system state. It is one of the most widely used filtering methods [24].

Kalman filter has five main equations. This first equation is used to predict the current estimated state.

$$X(t|t-1) = A\ X(t-1|t-1) + B\ U(t)$$

Where X(t|t-1) the estimated state at time k, in our case it is defined as $X(t|t-1) = \begin{bmatrix} \theta \\ \theta_b \end{bmatrix}_{t|t-1}$, where angle θ and the bias θ_b based on the measurements from the Acc-Mag module and gyroscope. X(t-1| t-1) the optimal state at time t-1, A and B are system variables. In our case, A is defined as $A = \begin{bmatrix} 1 & -\Delta t \\ 0 & 1 \end{bmatrix}$ and B defined as $B = \begin{bmatrix} \Delta t \\ 0 \end{bmatrix}$.

The second equation is to estimate the covariance.

$$P(t|t-1) = A\ P(t-1|t-1)\ A' + Q_k$$

Where P(t|t-1) is the covariance of X(t|t-1), in our case it is a 2×2 matrix: $P = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$. Q_k is the process noise covariance matrix. In our case, Q_k is defined as $Q_k = \begin{bmatrix} Q_\theta & 0 \\ 0 & Q_{\theta_b} \end{bmatrix}$

This third equation is to combine the estimate state and observed state.at time k.

$$X(t|t) = X(t|t-1) + Kg(t)\ (Z(t) - H\ X(t|t-1))$$

Where X(t|t) is the optimal state at time t, which is what we want. Z(t) is the observation of the true state X(t|t).

H is a parameter to measure the state of the system. H is given by: $H = \begin{bmatrix} 1 & 0 \end{bmatrix}$

Kg(t) is the Kalman gain at time t, which reflect the credibility of the innovation. It is defined as:

$$Kg(t) = P(t|t-1)\ H' \ /\ (H\ P(t|t-1)\ H' + R)$$

In this case, the Kalman gain is a 2×1 matrix: $Kg = \begin{bmatrix} K_0 \\ K_1 \end{bmatrix}$. R is the measurement covariance matrix.

The last equation is to update the covariance of X(t|t) to make sure the system can continue to work:

$$P(t|t) = (I\text{-}Kg(t)\ H)\ P(t|t\text{-}1)$$

Where I is called the identity matrix and is defined as: $I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

In our implementation, we use acc-MagAngle and gyro-Angle as two input parameters for our function, and it will return the current optimal orientation. Figure 5.6 shows the Sensor Noise Reduction with Kalman Filter (SNRKF) Algorithm for our system.

```
θb, P00, P01, P10, P11, θ ← 0
Qθ ← 0.01
Qθb ← 0.003
R ← 0.01
procedure KF (acc-MagAngle , gyroAngle)
        Z, K0, K1 ← null
        θ ← θ + gyroAngle
        θ ← θ – θb
        P00 ← P00 + dt * (dt * P11- P10 - P11 + Qθ)
            P01 ← P01 - dt * P11)
            P10 ← P10 - dt * P11)
            P11 ← P11 + dt *  Qθb
            Z ← acc-MagAngle –θ
            K0 ← P00 / ( P00 + R )
            K1 ← P10 / ( P00 + R )
            θ ← θ + K0 * Z
            θb ← θb + K0 * Z
            P00 ← P00 - K0 * P00
            P01 ← P01 - K0 * P01
            P10 ← P10 – K1 * P00
            P11 ← P11 – K1 * P01
            return θ
    end procedure
```

Figure 5.6 SNRKF Algorithm

5.4 Position Update Module

First, in order to calculate the current location of user, we need to calculate Δx and Δy in time Δt, which represents the change in location in an interval time. Then, we need to combine these values with the previous location.

As shown in Figure 5.7, The direction of y axis is North, and the direction of x axis is East. Since the range of θ is 0-360, there are four situations for calculating the current location. In our case, we knew the location of the previous point A and want to calculate the location of the current point B.

$0 \leq \theta < 90$: $X1 = X0+D\times\sin\theta$, $Y1 = Y0+D\times\cos\theta$

$90 \leq \theta < 180$: $X1 = X0+D\times\cos(\theta-90)$, $Y1 = Y0-D\times\sin(\theta-90)$

$180 \leq \theta < 270$: $X1 = X0-D\times\sin(\theta-180)$, $Y1 = Y0-D\times\cos(\theta-180)$

$270 \leq \theta < 360$: $X1 = X0-D\times\cos(\theta-270)$, $Y1 = Y0+D\times\sin(\theta-270)$

Where X_0 is the value of horizontal coordinate of A, Y_0 is the value of vertical coordinates of A. X_1 is the value of horizontal coordinate of B. Y_1 is the value of vertical coordinates of B. θ is the angle from AB to positive Y axis by anti-clockwise, which is obtained from Orientation Detection Module ($0 < \theta < 360$). D is the length of AB, which is the distance pedestrian has walked.

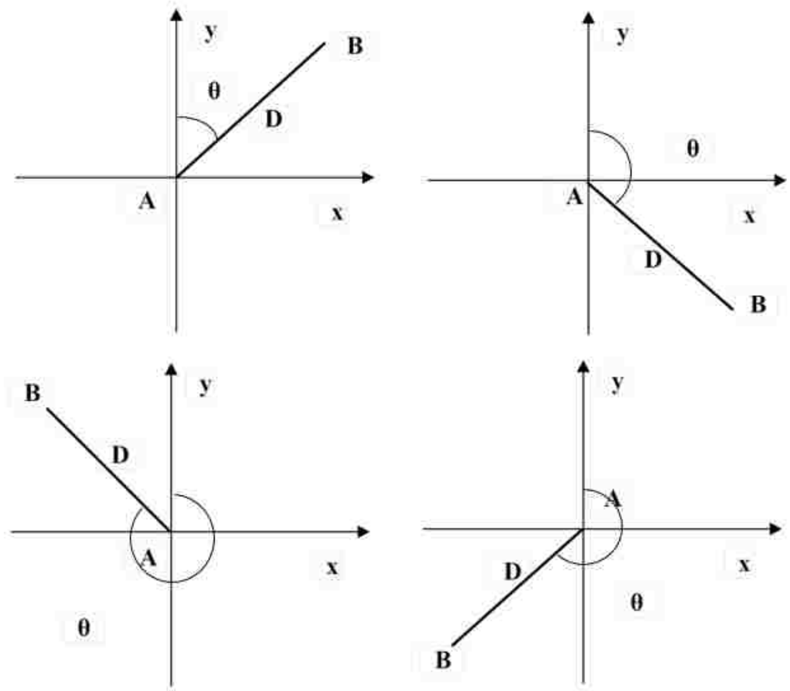


Figure 5.7 Different situation for calculating the current location

5.5 Map Design

Indoor map is essential for our application to let the user know where they are. We designed a function so that the user can upload an indoor map from the album of the smartphone. We create a canvas and make the map the background of the canvas so that we can paint the path of the user on the map while they are walking. We use the Marquette University library as an example, shown in Figure 5.8. The user can click the “SELECT MAP” button and choose a picture from local data.

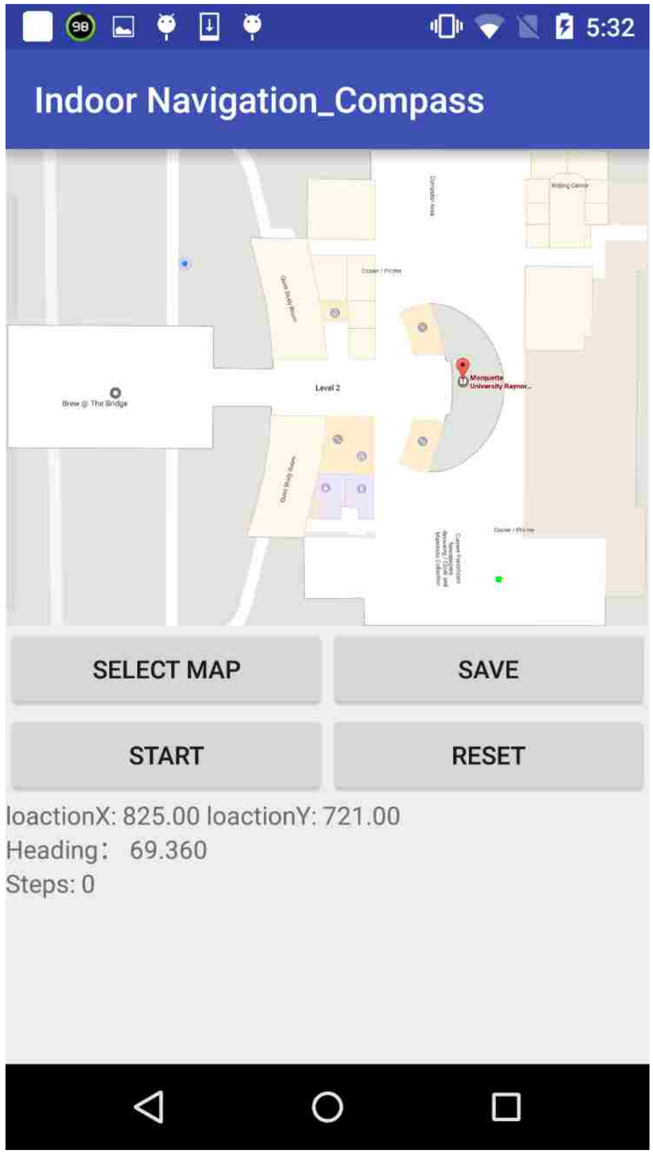


Figure 5.8 Map design

CHAPTER 6: EVALUATION

In order to prove the practicability of our research and the accuracy of our system, we invited 24 people from Marquette University to participate in our evaluation. We designed three main parts for the evaluation, including a survey, an experiment and a research interview. Each participant did all three parts of the evaluation. First, we asked participants to do a survey. Second, we asked the participant to test our application. After that, we performed research interviews to each participant. The survey and interview questions are included in the appendix.

6.1 Evaluation Methodology

The survey had 17 questions covering personal information, the understanding of and expectations of the indoor navigation system, and the opinions regarding power consumption. The goal of the survey was to prove the practicability of our research.

We evaluated the performance of our app by testing in two different buildings at Marquette University. We intended to answer the following questions: (a) How well our app is performing in an indoor environment; (b) How does the “Kalman filter” contribute to measure the rotation, and; (c) How well the step sensor is performing with regards to power consumption.

We collected real-time data sets from participators in different buildings for the evaluation. We prototyped our app on a Google Nexus 5 phone with the standard Android 4.4 to collect data from accelerometer, magnetometer, gyroscope and step sensor on smartphones.

One floor of different but typical buildings at Marquette University campus were selected to evaluate the performance of our app, including the first floor of Engineering Hall (EH-1F) and the third floor of Cudahy Hall (CH-3F). The initial position was assumed to be known. To evaluate our app performance, we used related orientation as the baseline. That is, given the test locations coordinates in the 2D point with a certain start point. To evaluate the performance of our app in detail, we designed four different solutions and compared the result of them. The detailed are specified in Table 6.1. The first is our app approach (denoted as $So1_1$). This solution used Kalman filter to combine the data from gyroscope, accelerometer and magnetometer to get orientation. It used step sensor to count steps. The $So1_2$ and $So1_3$ served to evaluate the contribution of Kalman filter. The last solution shows the performance of GPS in an indoor environment.

	$So1_1$	$So1_2$	$So1_3$	Sol_4
Kalman Filter	☑			
Gyroscope	☑	☑		
Compass	☑		☑	
Step Sensor	☑	☑	☑	
GPS				☑

Table 6.1 Different solutions for experiments

All four solutions were tested in each building. We assigned 12 people to each building, and each participant was assigned to test 3 solutions. Each tester took the phone and followed a certain path in the building. Our application recorded the information of a point every one second, including the coordinate and the heading.

We also tested power consumption. Since the most of indoor navigation systems are using accelerometer and gravity sensor to detect steps, we want to use step sensor to replace them and prove that our design saved phone battery life. In order to do that, we implemented another solution called Sol_5 by using the method described in [25] to detect step and keep all other parts the same as our $So1_1$. We tested these two solutions separately by walking around for 5 min and using the app "Gsam Battery Monitor" to monitor the power consumption of each app.

After the experiments, we held research interviews with all participants. The interview had 8 questions covering the experience of using the app and suggestions for improvement. The goal of the interview was to discover the shortcomings of our application and how we can improve future versions.

6.2 Results

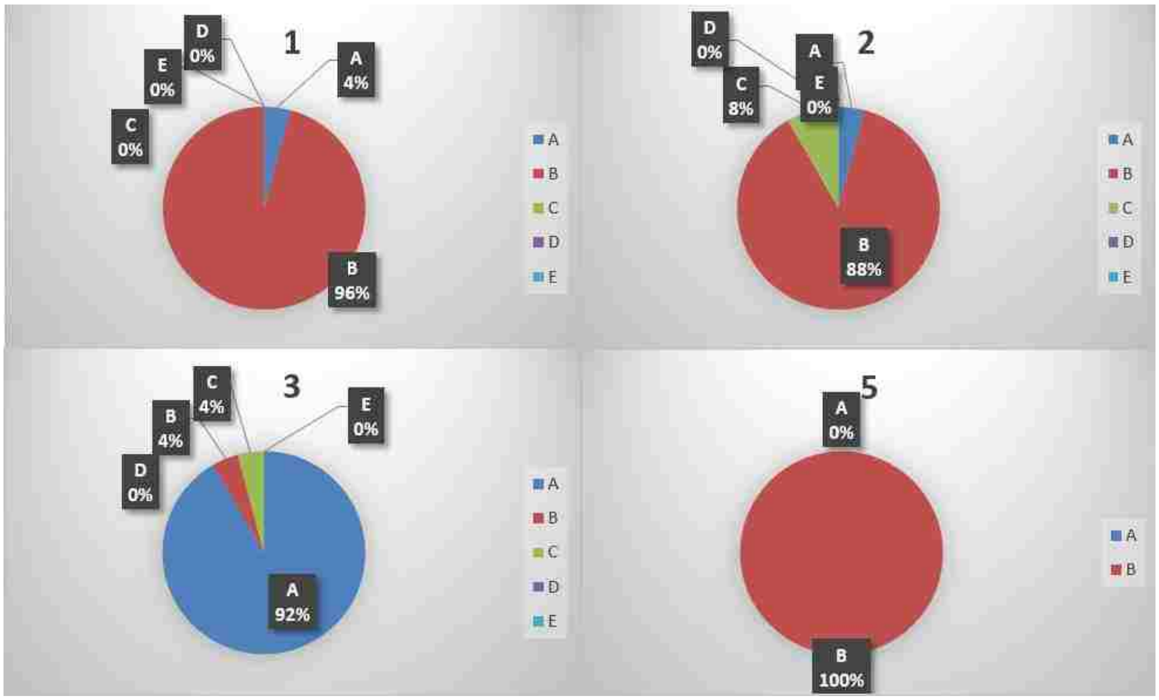
6.2.1 Survey

More than 90% of participants were between the ages of 21 to 30. First, we asked questions regarding how often the participant used navigation applications, what kinds of apps they use for navigation, and the reason they use this specific app. We found that all participants used a navigation app at some time, and 87.5% of participants used a navigation app very often. The most popular navigation application was Google maps, because they found it accurate and can show street traffic in real-time.

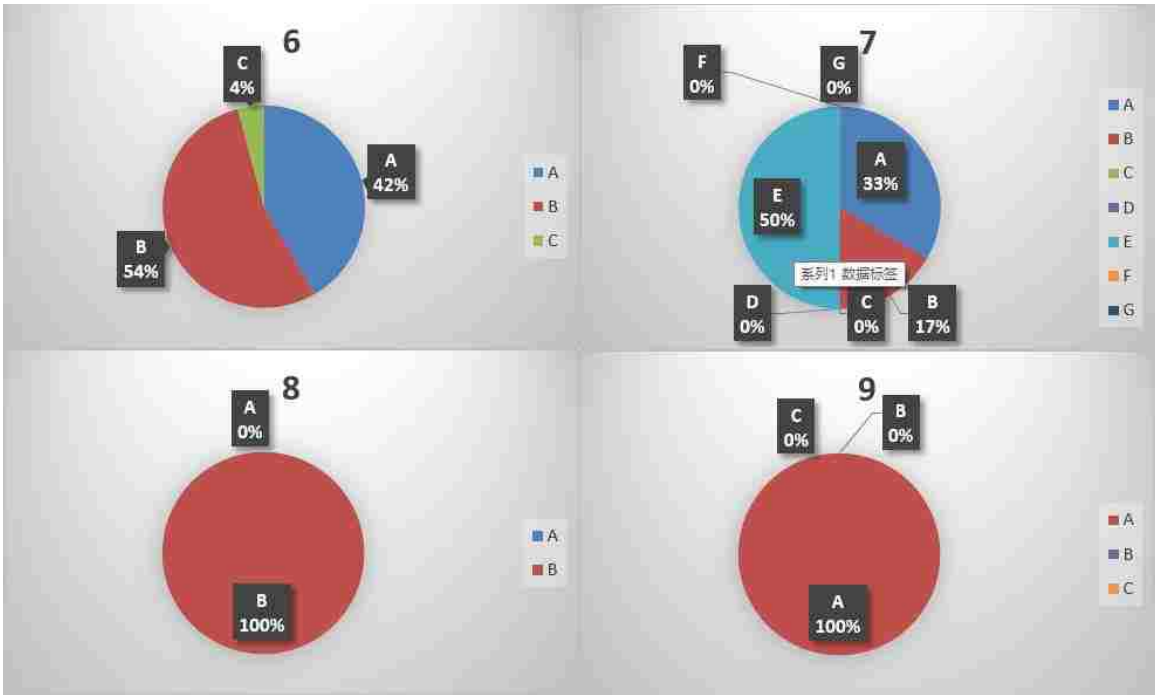
Then we asked questions about importance of battery consumption as an app feature. The questions asked included: *How often do you charge your phone? Do you think the power consumption of an application is important? If there is an app with the same function and has lower power consumption, would you replace the current one with it? About accuracy and power consumption, which one do you think is more important?* Consequently, 41.7% of participants charge their phone more than 2 times per day and 54.1% of participants charge their phone 1-2 times per day. Only one participant charged their phone less than 1 time per day. Moreover, more than 90% of participants thought power consumption was important, but increased consumption was acceptable if the application was very useful. 100% of participants thought that the accuracy of the navigation app was more important than the power consumption, but they would replace the current app with a lower power consumption application that has the same function.

Based on people's expectations for an indoor navigation application, the question set included questions such as: *What do you think indoor navigation application? Have you ever used an indoor navigation application before? What factors would affect your decision to use the indoor navigation application? What is an acceptable price for the app?* The results showed that no participants had used an indoor navigation app before, but 100% participants would like to try it. Most people thought accuracy and ease of use were both important for them when using such an application. The acceptable price was below $5.

In sum, from the survey, most people haven't use indoor navigation application, but all of them are willing to try it, which means that prospect of this app is promising. We also learned that the accuracy of a navigation application is most important to users. Power consumption was also important. Users preferred a low power consumption application than an application with the same function but high battery consumption.



(a)


6
C 4%
A 42%
B 54%
A
B
C
7
F 0%
G 0%
A 33%
E 50%
系列1 数据标签
D 0%
C 0%
B 17%
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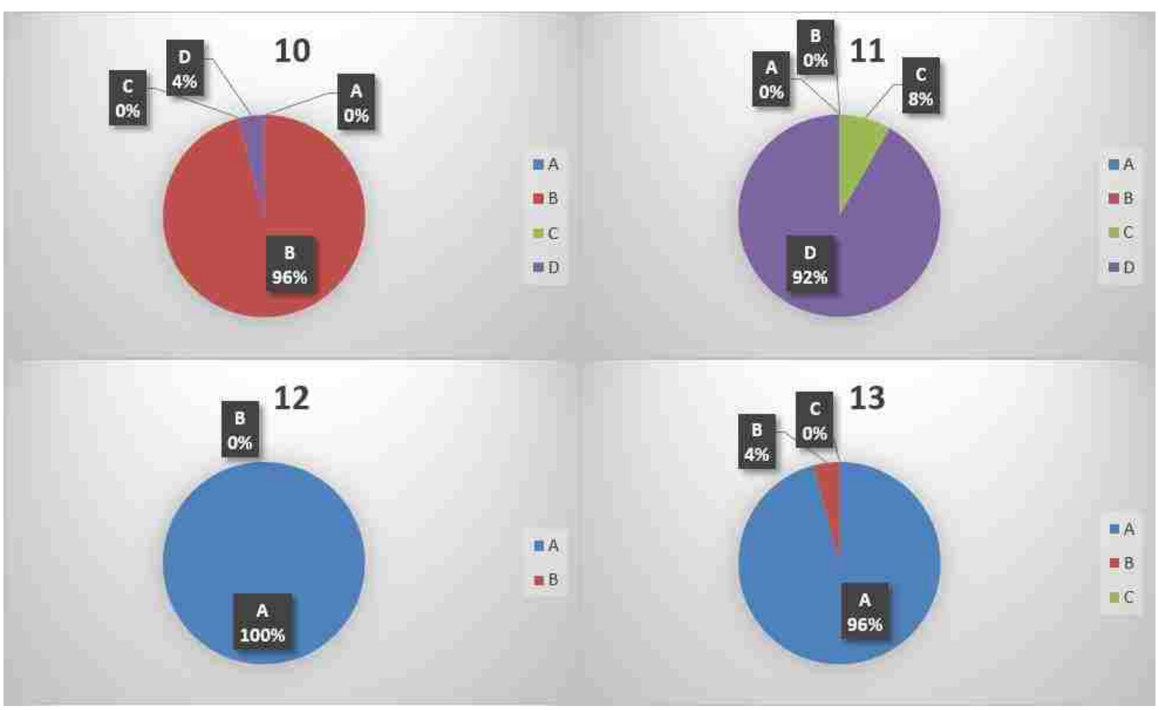
10
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C 0%
A 0%
B 96%
A
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11
B 0%
A 0%
C 8%
D 92%
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A 100%
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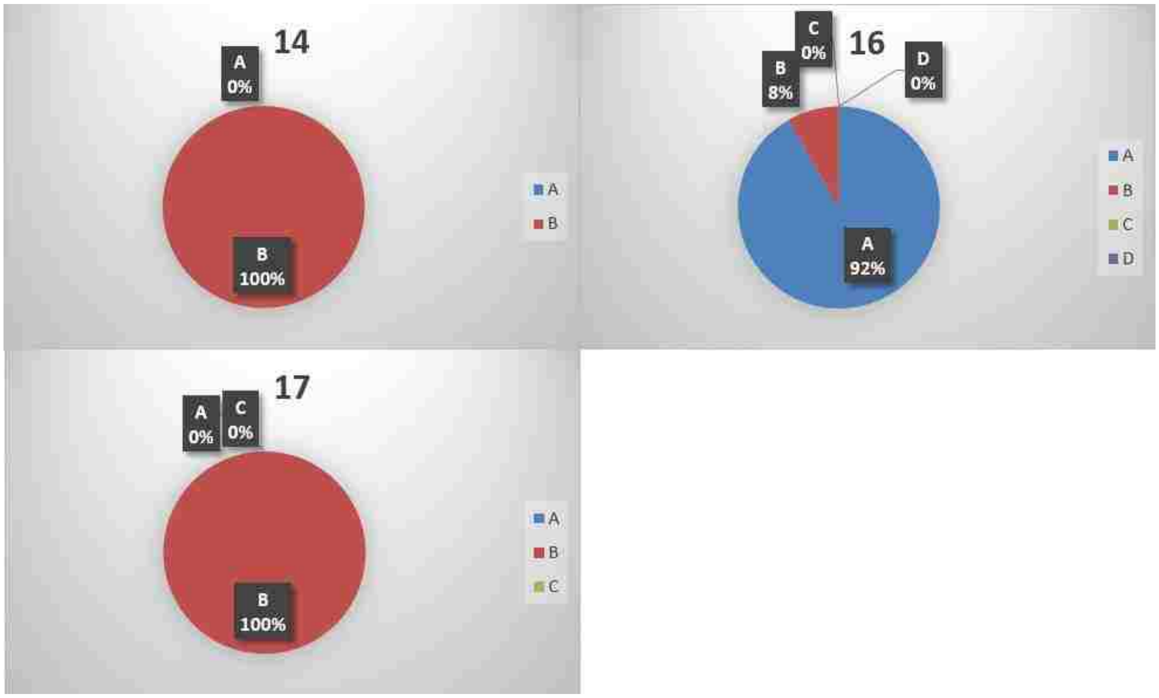
B 4%
A 96%
A
B
C

(c)



(d)

Figure 6.1 Results of survey with different questions

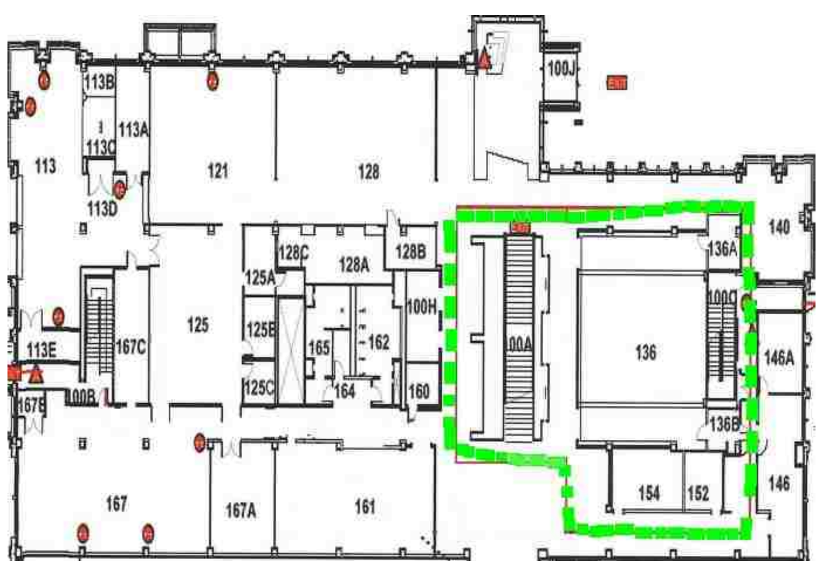
	4	15
1	It's popular	Can show the map of each floor
2	Accurate and easy to use	3D version
3	I need the function of navigation	Easy to follow
4	Other people recommend it to me, and I found it good to use	3D version
5	Can find where I want to go	Can show the optimal road
6	Easy to use	The map should show the name of each room
7	The interface is good	Can navigate in vertical way
8	The map is easy to follow	Can show the entire building
9	Easy to use	Can show emeragency exit
10	I don't know other navigation app	Can show building structure
11	It can show real-time road and traffic notification	Can navigate user to nearby entrance of road
12	Google is famous	Can show building general info

13	Can show the information of the place	No idea
14	Good interface	Show nearby elevators
15	It has better accuracy	Show food courts around
16	It can show traffic	Give tips for slippery floor
17	Easy to use	Can search the place
18	The map is clear to identify	Can show emeragency exit
19	The traffic updates in real time	Show the degree of crowding in real time
20	The signal is strong	Can show the name of store
21	Have off-line map	Have better accuracy
22	Can be use in different conuntry	Show where is the restroom
23	Have great reputation	Can show the distance between destination and me
24	Can show speed limit	Not only be used in indoor

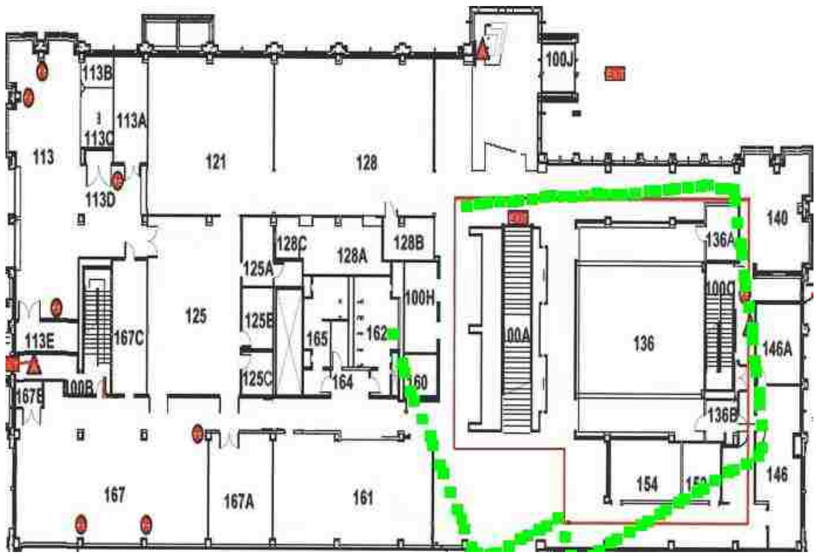
Table 6.2 Results of survey with questions 4 & 15

6.2.2 Experiments

Location Accuracy: During the experiments at Marqutte University buildings, we recorded the participant's track and the coordinates of each positions.

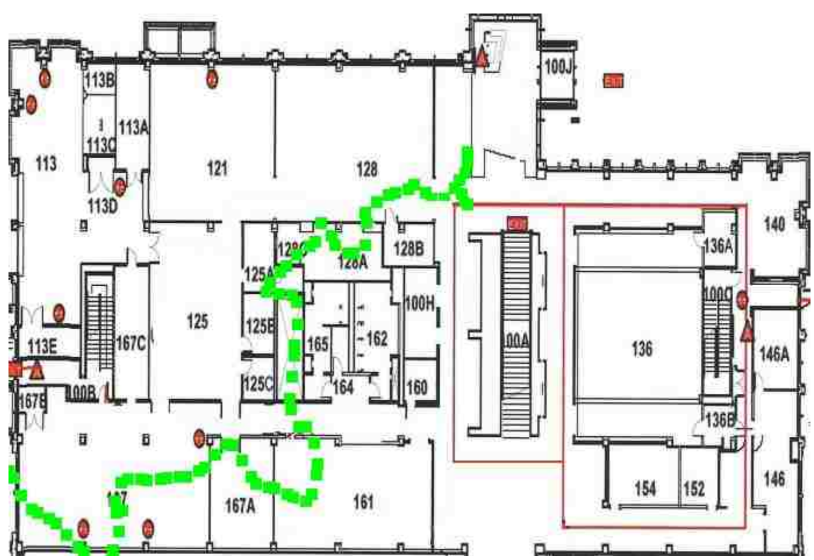


(a)



113B
113A
113C
113
113D
121
128
100J
128C
128A
128B
125A
140
136A
125
100H
100C
125B
165
162
113E
167C
100A
136
146A
125C
164
160
100B
167B
136B
167
167A
161
154
146

(b)



113B
113A
113C
113
113D
121
128
100J
128A
128B
125A
136A
140
125
100H
100C
125B
165
162
113E
167C
100A
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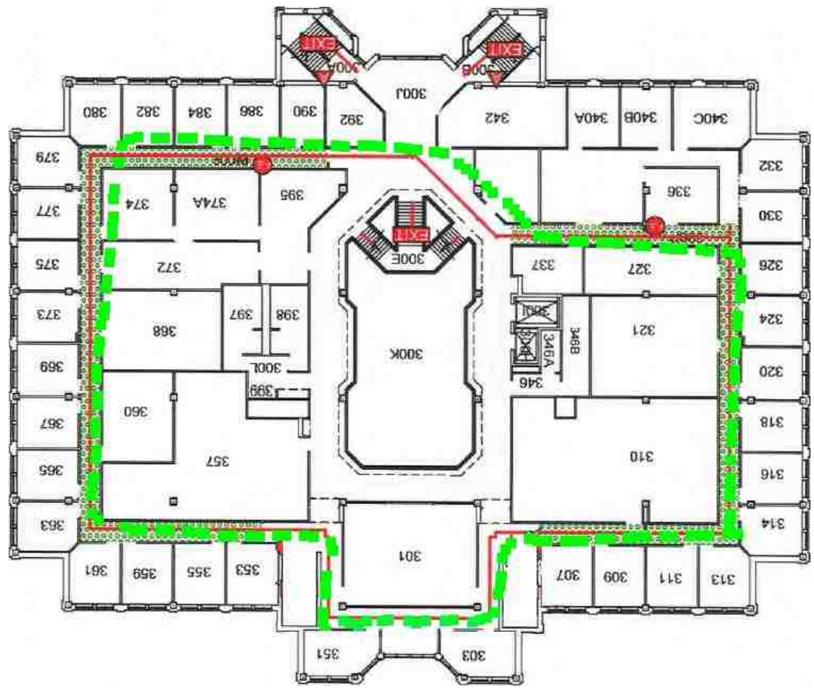
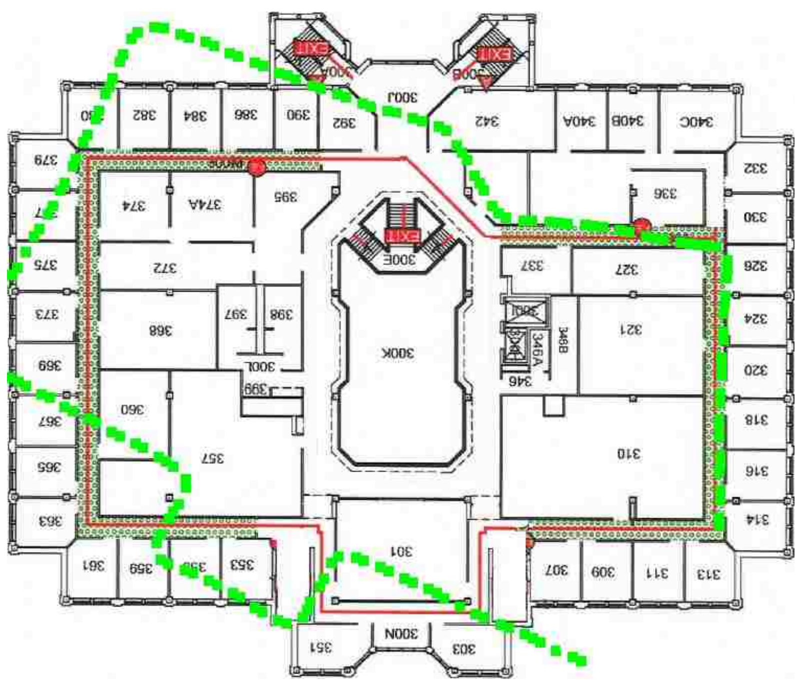
146A
125C
164
160
100B
167B
136B
167A
161
154
152
146

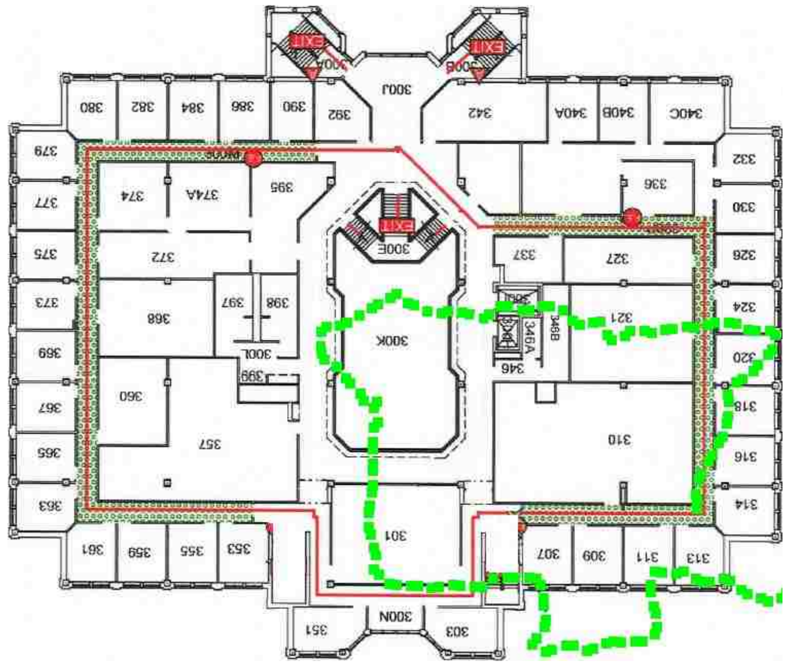
(c)



(d)



(e)

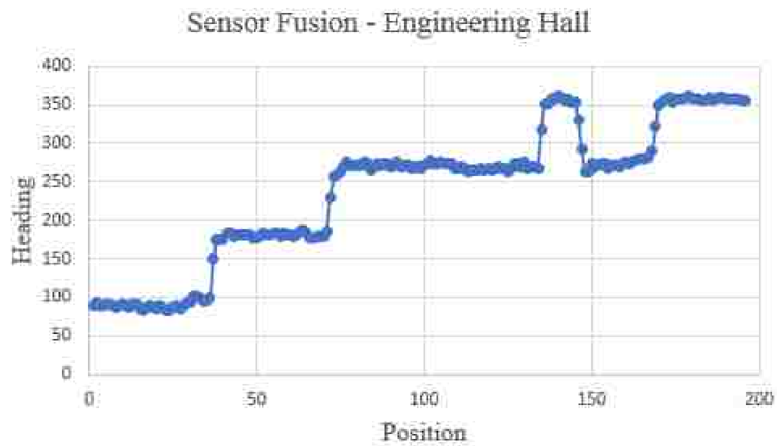


(f)

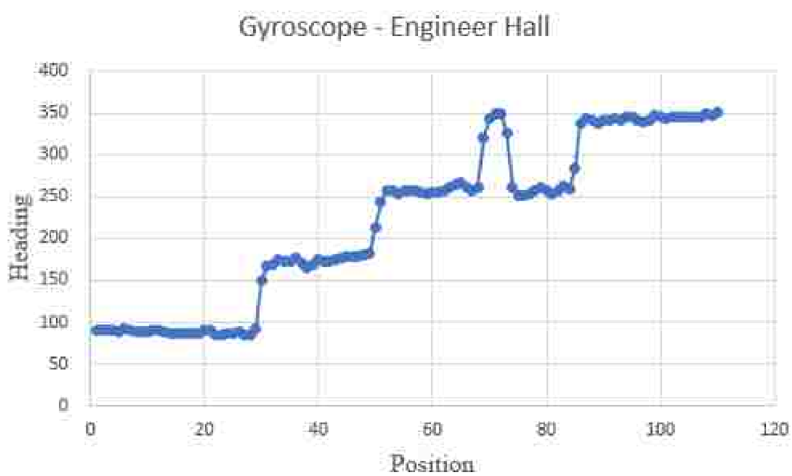
Figure 6.2 Track of participants in different building with different solution (a) $So1_1$-EH (b) $So1_2$-EH (c) $So1_3$-EH (d) $So1_1$-CH (e) $So1_2$-CH (f) $So1_3$-CH

Figure 6.2 (a-f) show the track of participants in different buildings with different solutions. The red line represents the real path that a tester walked. These six figures show that of all solutions, our system had the highest location accuracy in both buildings, and demonstrated a significant improvement over the other solutions. We also found that indoor environment had a significant influence on the compass, so that it did not work well. The GPS data remained almost unchanged and meaningless, therefore we don’t provide the graph for GPS solution.

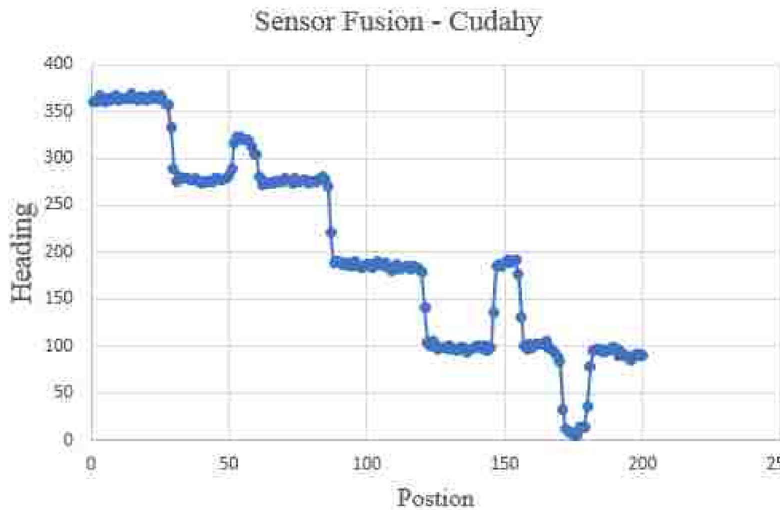
<u>Heading Accuracy:</u> We recorded the heading of each position during the experiments.


Sensor Fusion - Engineering Hall
Heading
Position
400
350
300
250
200
150
100
50
0
0
50
100
150
200

(a)


Gyroscope - Engineer Hall
Heading
Position
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120

(b)


Sensor Fusion - Cudahy
Heading
Postion
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200
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100
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0
50
100
150
200
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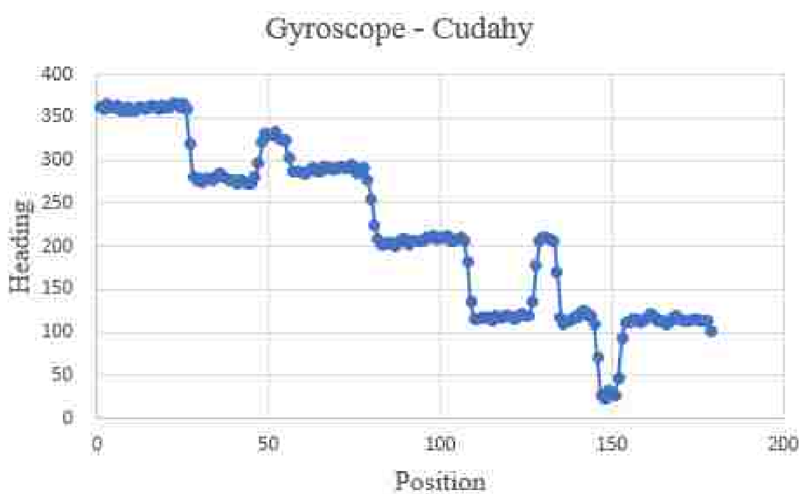
(c)


Gyroscope - Cudahy
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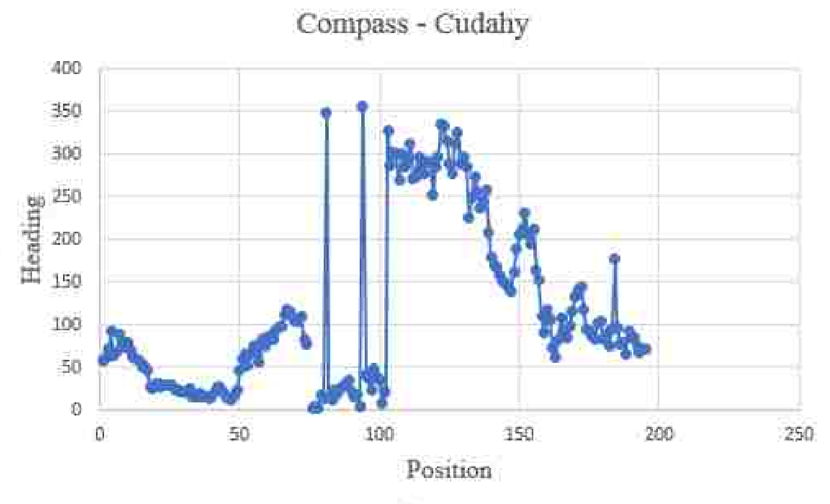
(d)



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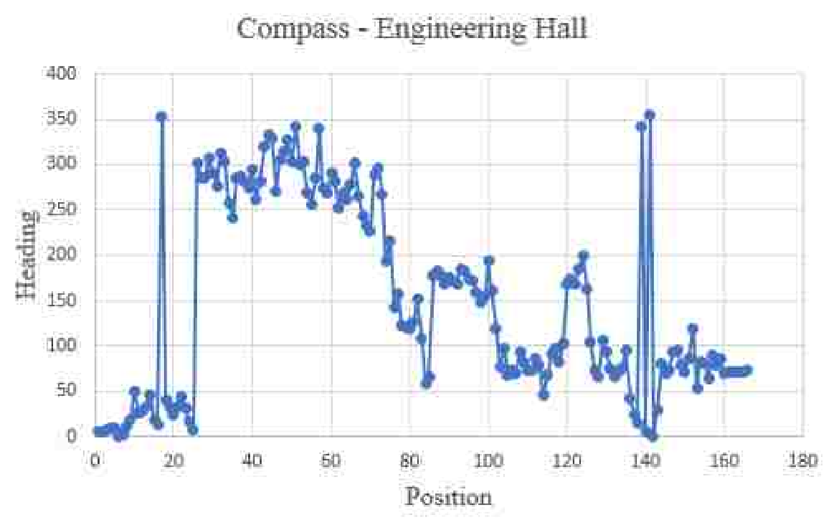

(f)

Figure 6.3 Head of participants in different building with different solution (a) $So1_1$-EH (b) $So1_2$-EH (c) $So1_3$-EH (d) $So1_1$-CH (e) $So1_2$-CH (f) $So1_3$-CH

As shown in the above figures, we found that in $So1_1$ and $So1_2$, the heading changed smoothly. In Sol_3, heading changed erratically and too fast. We also found that the change of heading is less that the actual turning angle. Compared with Sol_2 and Sol_3, Sol_1 showed high stability and reliability. Figure 6.4 shows the average heading error of Sol_1 and Sol_2.

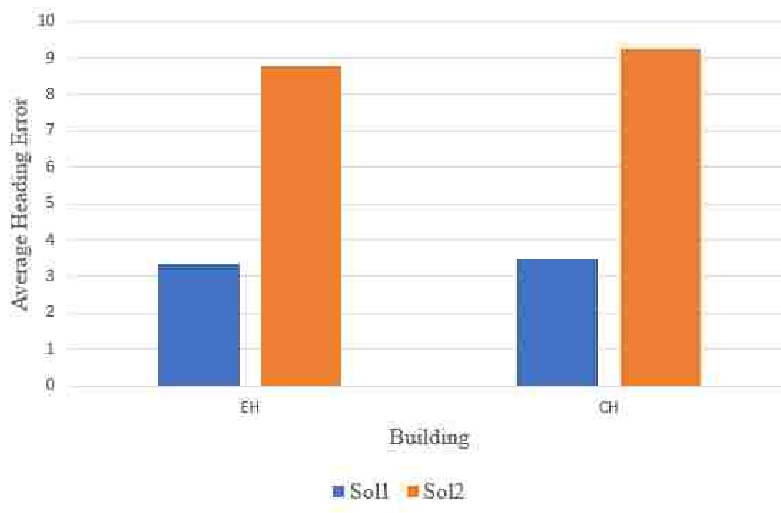

Figure 6.4 Average heading error of Sol_1 and Sol_2 in different buildings

From the above graph, the error of Sol_1 is significantly lower than Sol_2, which means the Kalman filter worked well and helped our system to achieve a high accuracy on the change of heading.

Power Consumption: Figure 6.5 shows the power consumption of Sol_1 (Indoor Navigation_1) and Sol_5 (Indoor Navigation_2).

Figure 6.5 Power consumption of Sol_1 and Sol_5

Sol_1 consumed less power than Sol_5. Since the only difference between Sol_1 and Sol_5 is the step detection, we conclude that the step sensor contributes to low power consumption.

6.3 Research Interviews

Based on the data collected in the interview, 91.7% of participants said they are satisfied with our navigation application, which shows this application has a great potential to be accepted by the users. Several factors may cause a high ratio of acceptance: On the one hand, the accuracy of the application has been improved a lot comparing with the other methods shown to the participants. In our case, Kalman filter is applied to combine the data from gyroscope, accelerometer and magnetometer to get orientation. The fusion of these elements forms a good combination which benefit improving the navigation accuracy a lot. From the feedback of the interview, there is no reporting of the signal lost in the test, what is more, it seldom shows up the phenomenon which the signal does not match the real route. On the other hand, most of the participants who took the survey have positive feedback for the operation of the application. This is actually a very important factor for user experience. The accuracy of the application may have a big influence on user whether they are willing to use it, while convenience make the user decide to use it or not.

Though mostly positive feedbacks are received, there are still lots of advices coming from participants who took the interview, one complaint focus on the interface of the application, though the functions are well defined, but several people mention the sequence is not clear explained. Generally, the design of the interface should be improved to make it more attractive for new users. For example, one participant said that there should be a menu and the background should be changed. The suggestions also include that there should have an instruction to help user operate the app, and have more functions to make the app better, like the map can be zoomed in or out.

For the Scenario of applying the application, most of the participants think that the most likely places to use this application may be shopping malls and other big public indoor locations which people may not familiar with the direction. Most of them agree that the application would be very helpful under that situation. Especially for people who are not familiar with the building and need to locate some exact spot in hurry. Several other participants also bring up the application might be applied such as fire accident and earthquake to save people’s lives.

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CHAPTER 7: CONCLUSION AND FUTURE WORK

7.1 Research Objectives Achieved

We built an indoor navigation system on Android platform to make people's lives more convenient and to help people solve emergencies that might happen. Our goal was make the system achieve high accuracy and have low power consumption. To reach our goal, we designed a sensor fusion scheme with accelerometer, magnetometer and gyroscope that are all inside the smartphone and combined the data from these sensors to get the high-accurate heading. Then we used step sensor, which consumed low power, and used Kim's algorithm [23] to calculate the distance for a period of time. Dead reckoning algorithm is implemented to update the user's position. Below are the features our system in its current state has achieved.

1. Android smartphone based application. Since we built our system just based on the sensors which are all inside the Android smartphone, we don't need to use extra sensors or some other technology, like Wi-Fi. A smartphone does not have to be expensive and they are used widely, which makes the application practical and can be used by the general public.

2. Sensor utilization. Our system does not only depend on one sensor to work. We build a sensor fusion scheme including various sensors and implemented a filter to get a highly accurate result.

3. Step sensor. Most indoor applications use accelerometer or gravity sensor to detect a step, which consumes a large amount of energy. We used step sensor instead of other sensors to save energy, which is important to smartphone users.

In this thesis, the sensor fusion scheme successfully achieve high accurate indoor navigation with Android tablets. Test results of the experiments using our system with Kalman filter shows that our system has successfully decreased the drift of gyroscope and achieved the optimal result of location information. The experimental results acquired in two buildings showed a high accuracy of 90% for our system. The experiment also showed that our system has a significant low power consumption feature.

7.2 Contributions and Broader Impact

The contributions of our work include a sensor fusion scheme for indoor navigation system on smartphone; a navigation algorithm that uses data from sensors to achieve indoor navigation; we successfully reduced the noise of data from different sensors by using Kalman filter; our sensor fusion scheme combines different sensors to improve the accuracy of indoor navigation; a low power consumption system that is suitable for Android smartphone.

The broader impact of this research is that the technology of this system can be easily used on other platform and applied to other industry areas. For example, with more accurate sensors, sensor fusion scheme can be used on an unmanned aerial vehicle or robot.

7.3 Future Work

One of the problems of our system is that the location of the first point is selected by the user, which means that if the point is wrong, all following location information would be wrong, except the shape of the path. Future extensions of this work include finding a way to solve that problem.

Moreover, we need more experiments to prove the performance of our system. In this work, we compared the performance of single sensor for navigation with our multi-sensor system. In the future work, we will compare the performance of our system with other related technology or applications.

Also, we need more functions to make the application easier to use. We want to combine various related technologies to our application and give additional options to users. We also need to improve the map function. For now, use can only use a map from their local sources, which means that they also need to know the scale of the map. In the future, we can build a map warehouse to store indoor maps and their scales. Users would just need to download the map from the warehouse. Users could also upload an indoor map to the warehouse.

Finally, we need more test data to fix the algorithm in our system. We did all experiments within the university, which seems insufficient. In future work, we will upload our application to the app store and let more people help us to test the performance of our system.

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APPENDIX

Survey Questions

1. What is your age：
   A. Under 20
   B. 21-30
   C. 31-40
   D. 40-50
   E. Above 50

2. How often do you use Navigation application？
   A. Extremely often
   B. Very often
   C. Moderately often
   D. Slightly often
   E. Not at all often

3. What kinds of Navigation application do you often use?
   A. Google map
   B. Waze Maps
   C. Scout GPS
   D. Sygic
   E. Polaris Navigation
   F. MapQuest
   G. Other __________________

4. Why do you choose this Navigation application?
   (Please write the most important reason)

5. Have you used or do you know other indoor navigation app? If yes, please indicate that.
   A. Yes ___________
   B. No.

6. How often do you charge phone?
   A. more than 3 times per day
   B. 2-3 times per day
   C. 1-2 times per day
   D. less than 1 time per day

7. As you know, which kind of application is the most power-consuming part in your phone?
   A. Games
   B. Photo& Video& Music
   C. Reading book & news
   D. Health & Food
   E. Kids & Education & Family
   F. Travel & Navigation
   G. Shopping
   H. Other_________

8. If you must delete the applications which were chose in last question, in order to save power, would you do that?
   Yes, (and why) __________________________
   No, (and why) __________________________

9. What is the most important factor for a navigation application?
   A. Accuracy
   B. Easily use
   C. Good user interface
   D. Other______

10. Do you think the power consumption of applications is important?
    A. Yes, absolutely it the most important thing for me
    B. Yes, but it not so important, if this application is very powerful
    C. No, I don’t care at all
    D. No, even though I need to charge phone often, I prefer a full functional application

11. Please rate accuracy of the navigation application that you are using
    A. 0-30%
    B. 31-60%
    C. 61-90%
    D. 91-100%

12. Do you think the power consumption and accuracy of navigation application which is more important to you?
    A. Power consumption
    B. accuracy of navigation

13. What do you think indoor navigation application?
    A. Yes, I’d like to try it.

B. It sounds interesting, but it is not useful for me.
C. I don’t know

14. Did you use other indoor navigation application before?
    A. Yes
    B. No

15. What functions do you think indoor navigation application should include?

16. What price is acceptable for an indoor navigation app?
    A. Free
    B. $ 1-5
    C. $ 5-10
    D. More than $10
    E. Other price range

17. What could be the reasons that delete your indoor navigation app from your phone?
    A. Too expensive
    B. I don't need it
    C. Other reasons

Research Interview Questions

1. How do you think about this navigation application?

2. Are there any situations that this application lose signal? （If there is, when and where）

3. Which part signal does not match the real route?

4. What’s your feeling when you use this application? How you think it is useful for someone who comes a new please first?

5. How you like the graphic user interface of this application?

6. How you think the convenience of this application?

7. In what situation do you think that you will use this application?

8. What suggestion do you have for this application?