A MOBILE BASED INDOOR POSITIONING SYSTEM FOR NAVIGATION IN JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

by

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Department of Geomatics Engineering and Geospatial Information Systems (GEGIS)

DECLARATION

I declare that this project is my own work and has not been submitted by anybody else in any other university for the award of any degree to the best of my knowledge.

Sign………………………………… Date………………………………………..

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CERTIFICATION

This project has been submitted for examination with my approval as the candidate's supervisor.

Sign……………………………. Date ………………………………………………

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Abstract

Global Navigation Satellite System (GNSS) has become a fundamental part of our day-to-day activities since it has successfully provided navigation and positioning services for the outdoor environment. However, the same is not the case for the indoor environment or built areas where satellite signals are lacking or are obstructed. Google maps has been in the front line in providing navigation services even for the indoor environment where it makes use of Wi-Fi signal strength method for localization and this requires a constellation of strong Wi-Fi routers that are not readily available in most of our buildings. This study aimed to solve navigation and positioning in any indoor environment, such as hospitals, universities, shopping malls, and complex buildings without using Wi-Fi routers. This was achieved by making use of an indoor positioning technology that involved integrating building floor plans and inertial sensors to develop a mobile application with positioning and navigation capabilities. The inertial sensors used include the built-in accelerometer and gyroscope in smartphones that provided the user's position and heading direction hence the ability to position and navigate. The result was an inexpensive mobile application that displayed the sensor's activity, an outdoor map overlaid with the building's floor plan showing various points of interest, route direction and the user's current position. This study successfully used mobile phone sensors with map assistance to provide floor to floor indoor positioning and navigation services within a building in Jomo Kenyatta University of Agriculture and Technology (JKUAT).

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Acronyms and abbreviations

GNSS Global Navigation Satellite System

GPS Global Positioning System

IPS Indoor positioning system

RFID Radio Frequency Identification

UWB Ultra Wide Band

WLAN Wireless Local Area Network

RSS Received Signal Strength

RTOF Received Time of Flight

TOF Time of Flight

TOA Time of Arrival

TDOA Time Difference of Arrival

EDR Enhanced Dead Reckoning

FSM Finite state machine

WSANs Wireless Sensor and Actuator Networks

Wi-Fi Wireless Fidelity

KNN K-Nearest Neighbor

SVM Support Vector Machine

ArchiCAD Architectural Computer Aided Design

JDK Java Development Kit

ELB Engineering Laboratory

JICA Japan International Cooperation Agency

1. Introduction

1.1 Background

Location detection has been instrumental and successful over time by providing useful information based on the user's current location or the desired location. It has had a significant impact on improving and easing the day-to-day life activities by providing guidance, navigation, and mapping. However, this has been the case for the outdoor environment and not the indoor environment (Yim, 2015). Location identification in the outdoor environment makes use of the GNSS or other satellite-based location systems, but for the indoor environment, the GNSS signals are obstructed by the walls causing their attentuation and loss of potential (Motte et al., 2011). Hence the need for the development of indoor positioning systems that will allow users to navigate within buildings.

Globally, indoor positioning has become a hot research topic; a number of systems have been developed to provide the localization service using various technologies. In Kenya, most people use google maps for navigation and wayfinding for the outdoor environment and while google maps have introduced indoor positioning to a certain scale in countries like Japan, Italy, Malaysia, South Africa and Nigeria Kenya is yet to experience such services.

An indoor positioning system is a system that provides an accurate and real time position of a person, a device or an object within an indoor environment. An indoor positioning system deals with small areas meaning it generally requires a high level of precision and accuracy. There are various metrics to look out for when designing an indoor positioning system to determine its performance. These performance metrics include area of coverage, availabilty, cost, privacy, scalabilty and accuracy. Depending on the preferred metrics one can decide on the type of indoor positioning technology to use. Generally the indoor positioning technologies are grouped in many different ways by many researchers and currently they have been classified into; Radio Frequency Identification (RFID), Ultra Wide Band (UWB), Zigbee, Bluetooth, infrared, Wireless Local Area Network (WLAN), ultrasonic and Cellular Based(Al-Ammar et al., 2014).

Indoor positioning systems (IPS) technology makes use of a network of devices to provide location information in areas where the GPS or other satellite systems may fail or lack precision. Such places include the inside of buildings, airports, museums and underground locations. Indoor positioning systems can also be used for various purposes in hospitals; tracking and monitoring elderly patients whereby they have sensors attached to their wheelchairs, tracking hospital equipment that is quite expensive to prevent thefts and providing quick directions in case of an emergency.

An indoor positioning system is made up of at least two hardware components, a signal transmitter and a measuring unit. The signal transmitter sends out the signal, and the measuring unit receives the signal, measures its properties, and gives the output; it is the intelligent component in the system. There are four different system topologies, the remote positioning system, the self-positioning system, indirect remote positioning, and indirect self-positioning system(Liu et al., 2007).

In the remote positioning system, the mobile hardware is the signal transmitter while the fixed hardware is the measuring unit. The transmitted signals and results are received and collected by the measuring unit respectivley. The location of the target point is calculated in a master station. The self-positioning system is made up of fixed signal transmitters and a mobile measuring unit. The measuring unit receives signals from various transmitters of known location, and from those signals, it can compute the location. For indirect self positioning, the self positioning system sends the measurement result from the remote site while for the indirect remote positioning, the remote positioning systems sends the measurement result to a mobile unit. Both systems make use of a wireless data connection to send the results.

1.2 Motivation and problem statement

There is an increase in human made structures such as buildings or underground facilities, especially with the rapid increase in urbanization (Yim, 2015). The buildings are becoming larger and more complex over time proving difficult for people to find their target locations; therefore, the need for location-based services for the indoor environment is growing stronger and the services are of huge market potential. Buildings require an efficient emergency response system in the case of an emergency or a disaster such a fire therefore proper knowledge of the buildings' fire extinguishers, assembly points, evacuation paths and emergency exits is vital (Depari et al., 2018).

Kenya is only at its early stages in urbanization, and this is expected to increase, meaning there will be an increase in the built environment. Given that people spend about 80%-90% of their daily time indoors, there is a need to make indoor spaces more comfortable and easier to navigate. A great advantage is that indoor mobile communication is very high as 70% of mobile phones are used indoors and 80% of the communications are made indoors(Xia et al., 2017).

GPS one of the most prevalent Global Navigation Satellite Systems has been excellent in providing accurate and reliable location information; it has greatly impacted daily life activities such as finding the nearest hospital, the closest taxi or even finding friends (Dari, 2018). However, this has not been the case for the indoor environment since the GPS signals cannot penetrate most of the building materials, or in the case, they do the signals quickly weaken due to the walls or objects within the building (Al Delail et al., 2013). For a GPS to perform a triangulation, there must be a line of sight from the satellites, but this is difficult and next to impossible inside a building. These limitations cause the GPS to be unreliable, unavailable, and inefficient for indoor positioning (Ja'afar et al., 2013).

1.2.1 Justification

There is a need for turn-by-turn indoor directions within complex buildings, universities, airports, and shopping malls. In hospitals, quick and efficient asset tracking for equipment like wheelchairs is important and can save lives. Facility management or tracking of staff activities within an office can improve an organization's overall performance (Laoudias, 2012).

At Jomo Kenyatta University, there is a need to make navigation within the buildings easier especially with development of large and complex buildings. This will save time for the students, the staff and visitors since they can easily find their way into their target destinations such as lecture rooms, offices, hostels and laboratories.

The indoor positioning systems heavily rely on wireless technology, and with the massive availability of smartphones with wireless connectivity, it has become possible to develop an IPS without additional hardware. The smartphones contain sensors such as GPS receivers, Wi-Fi, accelerometers, gyroscopes, cameras, and digital compasses that can be used for indoor positioning.

The indoor positioning systems use floor plans; therefore, there will be a regular update on the buildings' floor plans to give the user the best possible experience and this will help overcome the challenge of accessing digital floor plans.

1.2.2 Research identification

This research aimed to develop an indoor positioning system that will enable a smartphone user to navigate specific buildings at Jomo Kenyatta University. This was achievable through the following specific objectives:

Research objectives

1) To create floor plans for the target buildings that will be used as the indoor maps for navigation.
2) To access and process real time phone sensor data that will be used to identify the user's position and enable navigation within the specific buildings.

Research questions

The following questions are formulated with respect to the aforementioned objectives:

1) Will the digital floor plans match with actual building on the ground?
2) Can phone motion sensors provide the user with their accurate position and navigation?

2. Literature review

The development in technology has made the development of indoor positioning much easier because of the availability of smartphones and wireless technology. There are many technologies that are used in indoor positioning systems with different performance metrics as earlier stated. For this particular study the most suitable technologies to use will be Wi-Fi technology or inertial sensors, given that the other technologies require specific hardware components that are not available in the university and would be costly to acquire.

2.1 Inertial sensors

Inertial sensors technology involves making use of sensors such as the accelerometer, gyroscope, magnometer and pressure sensors that are readily available in smartest phones. This makes it an excellent technology for indoor positioning systems since the hardware needed is readily available and easy to use. In Anapji an android app has been developed using inertial sensors and dead reckoning for indoor and outdoor positioning by tourists. The park contains an artificial pond surrounded by about ten viewpoints, using the app a tourist can navigate within the park whether they are inside or outside a building.

The main components of the system include the smartphone, the point of interest (POI) web server, the map server, the floor map repository, the Indoor POI database (DB), and the outdoor POI (DB). The databases contain points of interest for both the indoor and outdoor while the servers are the source of information for the POI and floor plans needed for the application. The floor map repository is connected to the map server, and it contains the floor maps of the buildings along the pathway.

The outdoor positioning is provided by the GPS, while the indoor positioning is achieved using enhanced dead reckoning that uses the sensors inside a smartphone. Once a user enters a building or built structure, the entrance is starting point of the dead reckoning process (Shim et al., 2015). There is a set threshold that determines if the user is within the building or not. The GPS signals are collected every second, then an average of the last five accuracy attributes is calculated. If the result is greater than the set threshold, the user considered to be inside the building. The EDR uses the accelerometer values to count the steps and determine the orientation from the acceleration and orientation sensors. From the orientation values, the direction is determined. The other advantage of using EDR is that it can determine whether a user is in motion or not. In the system, the Indoor trace thread performs this function and determines the steps. Whenever the user stops, an update is made to the system indicating the point as a position of interest; this provides 95% accuracy for the indoor positioning from the 30 tests done using the system.

A smartphone indoor positioning application, was developed using dead reckoning on a smartphone since smartphones are equipped with accurate sensors (Yim, 2013). From the sensor values, one can estimate distance and direction; the current estimated location can also be represented on a floor map. The system is designed to recognize the user's current location, the moving status, and watching status. The sensor values collected every 50 milliseconds calculate the standard deviation of the last 20 y-axis accelerometer values. There is a threshold set such that if the calculated standard deviation is less than the set threshold, then the user is not moving. The system used the modified Finite State Machine (FSM) that involves using a negative peek, and a positive peek to determine the location at every step. It is such that if the input at, say, s1 is more significant than the negative peek, then the next state is s2, but if the input is less than the negative peak, then the state is stationary. This provides a sequence of steps hence locations on the screen that are displayed on the floor map. The other part of the system is the watching status, and when the user holds the smartphone in a portrait orientation, then it is considered that they are watching an exhibit (Yim, 2013).

Smart Syndesis is a system developed to provide indoor location information in a smart building environment through wireless sensor and actuator networks (WSANs). It uses a smartphone user's location to trigger the retrieval of environmental measurements, which will activate the actuators automatically to perform an activity such as switching on or off lights, fans, printers. The system comprises of a wireless sensor and actuator network management test bed, indoor localization and navigation engine, and a human-centric automation module(Zhao et al., 2017). The indoor localization and navigation engine provide a smartphone user's location in real-time using sensors and Wi-Fi received signal strength (RSS). The other component is the floor plan component that contains the floor plan information.

In the inertial measurement unit, two sensors are used the accelerometer and the geomagnetic field sensor. At time *t,* when the user executes a new step, the displacement of the user is determined using a motion vector M_{vt}; $M_{vt} = [\theta_t, l_t]$ where θ_t is the heading orientation, l_t is the length of a stride at a time. The heading orientation is determined by the digital compass from the geomagnetic field and the accelerometer sensors, the stride length can vary, but it is assumed to be constant in the tracking algorithm. The floor plan component contains all the information about the indoor environment in terms of floor plans. It defines the area of interest while defining the constraints such as inaccessible areas, and it is used to improve the overall tracking accuracy.

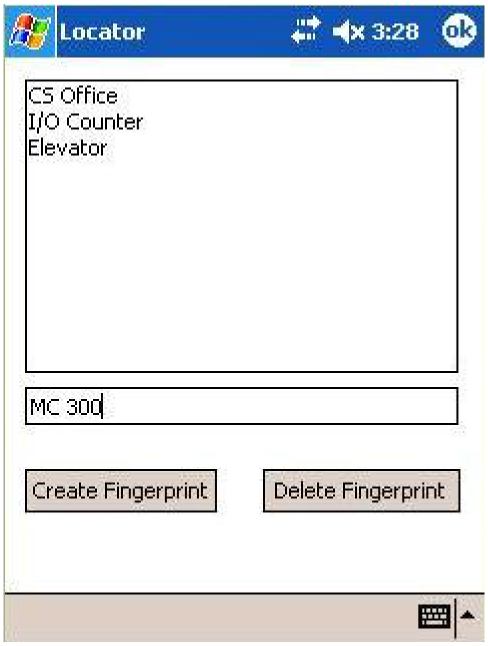
For the Wi-Fi received signal strength, there is the radio information component and the data fusion component. In the Radio information component, the RSS information is converted into range estimation values, and for higher accuracy, the Non-Linear Regression (NLR) model is used. The data fusion component uses the Wi-Fi information, floor plan information, and the PDR together to provide the real-time indoor tracking capability. The Wi-Fi information was obtained using the fingerprinting approach, whereby the signal strengths from multiple access points were used to build Wi-Fi fingerprints for supervised learning. It contains two phases: the offline training phase and the online localization phase. The offline phase is used to build the fingerprint database that contains the Wi-Fi RSS vectors for each room from the Wi-Fi access points. Room recognition is done in the online phase by searching for the closest match of the test data using the information that had been collected and the current Wi-Fi RSS vector. Some of the algorithms used include the K-Nearest Neighbor (KNN) and Support Vector Machine (SVM) such that when a localization command is executed in the map, both algorithms are used, and in the case of a classification mismatch, the process is repeated using the new WI-FI- RSS vector. (Zhao et al., 2017)

2.2 Wi-Fi technology

Wi-Fi works as an indoor positioning technology by making use of the TOF rather than the RSS. Using at least three access points and the TDOA measurements it is possible to calculate the location of an object or person within 3 meters. There is a great popularity in using Wi-Fi as an indoor positioning technology and this can be attributed to its accuracy and relative low cost compared to other technologies. The western locator is a Wi-Fi-based system that aims to provide indoor positioning while maintaining a balance in accuracy, cost, and coverage by the system. It works by mapping fingerprints of the received signals at given locations. Using a preselected location, say L, a fingerprint is collected and stored, but for an unknown position, the fingerprint from a preselected position that best matches the fingerprint taken for x determines the location. The algorithms are used to find the best match of the fingerprint taken at the current position and the preselected set of fingerprints associated with that position. For the first case, the matching algorithm the input includes a fingerprint of the current position of the device L, and the preselected set of fingerprints x. the fingerprints in L and x are compared to determine the similarity, in the case that a device is not detected the constant low represents it. The algorithm contains the score function and the adjust function. The score function is used to compute the sum of signal strengths, the higher the signal strength of the higher the value returned by the score. The adjust function is used to address the issue of fluctuating signal strengths at the access points.

Updating of the fingerprints of predetermined locations can either be done by adding or deleting access points, and it requires the use of weights since they determine the emphasis to be put on the current position. The design contains a scanner class, fingerprint class, and manager class. The scanner class monitors a specific type of device. The object of a class will maintain a list of the detected devices and each of the detected device's signal strength. Once the scanner object is created, the developer can create the fingerprints using the get fingerprint method, from which it will obtain a list of the wireless access points that have been currently detected. The list is generated using the BeginScan method that scans the client device's environment for any signals, and the End scan terminates the scanning. The last Wi-Fi signal that was detected is provided to the Scanner object and the other signals that were detected and maintained until the scanner object is destroyed.

The Fingerprint class stores and retrieves the fingerprints using symbolic names that are easier to identify with rather than numbers. The manager class allows the developers to perform actions on the fingerprints. First, the fingerprint data is stored in a file using the WriteData method and a corresponding method for reading the fingerprint data is available in the application. The manager class computes the similarity number and determines which fingerprint most accurately stores the current location. Once the fingerprint is obtained, the getTopFingerprints method obtains the symbolic name that closely matches the current location's fingerprint from the preselected positions. After comparing the positions and assigning the symbolic names, the current position is updated using the updateLocations (Phillips et al., 2014).



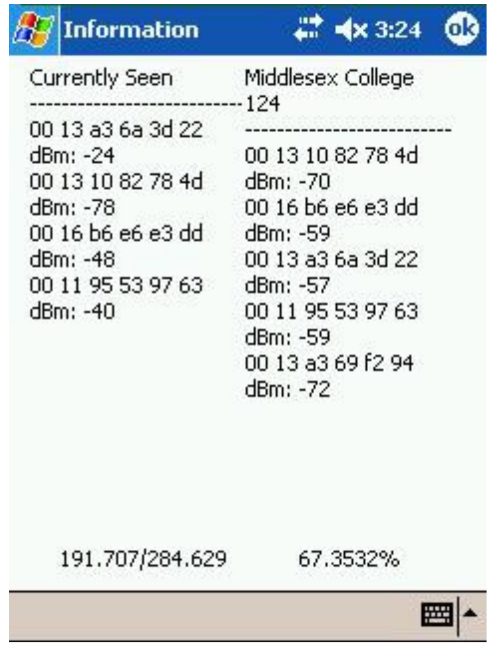


Figure 1: Fingerprint management (Phillips et al., 2014)   Figure 2: Display of fingerprints (Phillips et al., 2014)

The system was tested in Middlesex College, building its basement on the first floor and the second floor. The system could identify systems that were five to ten meters.

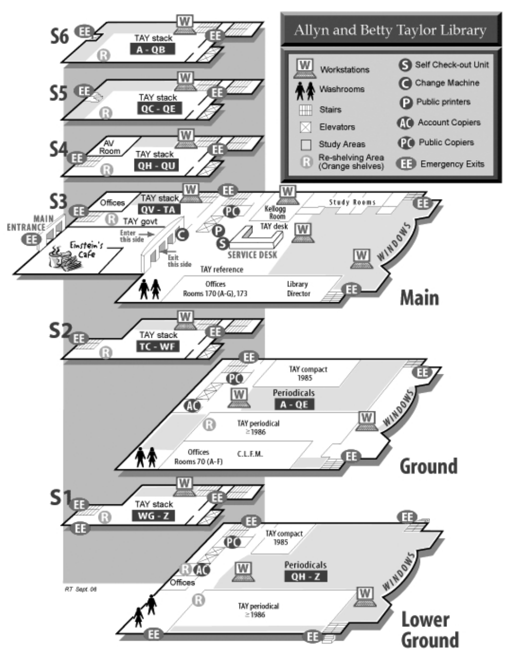


Figure 3: Output by the system (Phillips et al., 2014)

A mobile-based indoor positioning system was developed using the information from the access points' received signal strength to determine the location in the University of Atma Jaya. To increase the accuracy, they used the K- Nearest Neighbor (KNN) method. The first step is to collect the access point's data within the building and any other relevant room data.

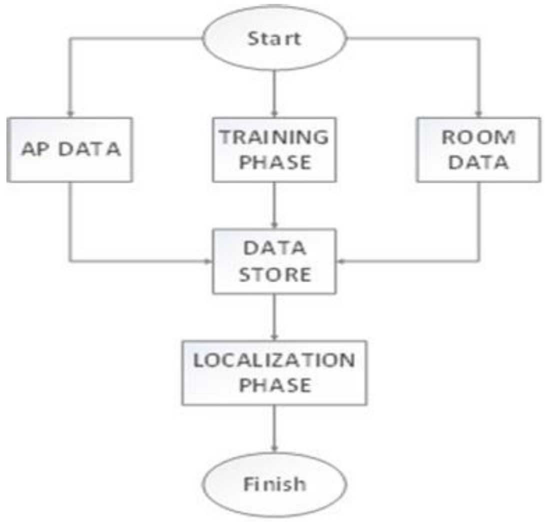


Figure 4: Methodology to obtain location (Phillips et al., 2014)

In the location recognition stage, the app will detect all the APs around the device, and the app will detect the Basic Service Set Identifier (BSSID) or mac address of an AP. It will use the mac address as an identifier and detect the Received Signal Strength Indicator (RSSI). The three access points with the best signal will be listed. This stage is critical since the system will identify the device's position and afterwards map it accurately. After that, the system will sort the data collected based on the best value of RSSI. The system then will perform calculations by calculating the existing data, and then the best results will be compared with the data that has been in the database, which will then be used as a reference location of the device. The next step will be to add the room data, and the AP data detected, in which we will have the three access points.

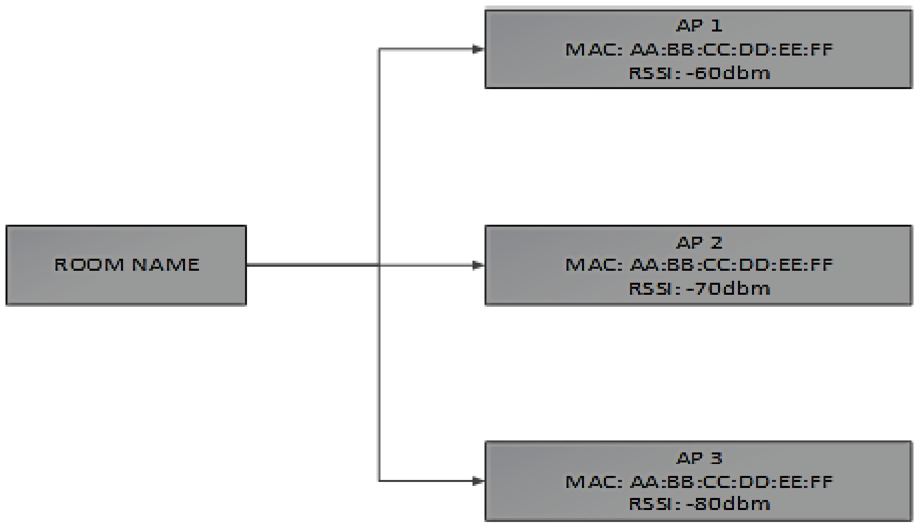


Figure 5:The relation between a room and access point data (Phillips et al., 2014).

Using the KNN method will also be used in the calculation section to obtain the mean absolute error (MAE). After the calculation process is completed, the system will compare the two values that have been obtained. From the calculation, the results of the first row yield the smallest number of mean absolute error MAE1 = 4.33, and the first line of data then can be referred to as the data of the device's location. The next step is to take the room data per the existing room ID on the first line of data. This will give the final location with the room name.

Room ID	Room Name	Floor	Building Name
3	Discussion Room II/5	2	Building No.3 Bonaventura

Table 1: Final results showing the rooms

2.3 Positioning algorithms

There are various IPS technologies that are used to obtain the location of a mobile or immobile device. It could be through the use of sensors or communication technologies, which may further be classified based on the location positioning algorithm or the physical layer infrastructure. For the location positioning algorithm, it refers to the types of measurements of the signal that are used to determine the location. It includes, but not limited to, time of flight, angle and the strength of the signal. Infrastructure refers to the wireless technology used to communicate with devices.

Some of the positioning algorithms include triangulation, proximity, and scene analysis.

2.3.1 Triangulation

In triangulation, triangles' geometric properties are used to estimate the target location; this can be through lateration or angulation. Lateration, or the range measurement technique, uses the target object's measured distances from multiple reference points to estimate its position. The range estimate measurements include the received signal strength (RSS), time of arrival (TOA), or the time difference of arrival(TDOA), the distance can be computed by multiplying the velocity of the radio signal or the attenuation of the emitted signal strength with the estimates.

The received signal strength is the signal's field intensity measured at the receiver. This method is also known as the signal attenuation based method since the distance estimated is dependent on the signal propagation. There is a difference in strength between the transmitted signal and the received signal caused by several things such as multipath. This is whereby there is a mix between the signals and their reflections, or the received signal does not come from a line of sight, therefore causing a greater travel distance than that of the actual direct path. In addition to that, the time and angle of arrival is also affected, causing a further decrease in the accuracy of the estimated location. Using theoretical or empirical signal propagation models, the difference in strength between the transmitted signal and the received signal is converted into a range estimate. However, the parameters used in the models are site-specific, and they do not always hold. The accuracy of using RSS can be improved by using remeasured RSS contours centered at the receivers or using measurements from various stations.

Roundtrip time of flight (RTOF) is another lateration technique that uses the time of flight of the signal from the transmitter to the measuring unit. It uses the same measurement technique as TOA, but it uses a relative clock synchronization requriement that is more moderate than the TOA requirement. The measuring unit measures the roundtrip propagation time once the target transponder responds to the interrogating radar signal. The delay caused by the responder is meant to provide range measurements, but it is difficult to measure the exact delay. It can be ignored in long-range systems or medium-range systems, but for the short-range systems, it must be taken care of, and this can be done using positioning algorithms for TOA.

The received signal phase method, also known as the phase of arrival, is a method that uses the phase difference to provide range estimates. The transmitter stations are placed within an imaginary cubic building, the transmitter stations are assumed to emit signals of the same frequency, and a finite transit delay is used from each of the transmitters to the receivers; it is a fraction of the wavelength. The range estimate can be measured as long as the signal's wavelength is longer than the cubic building's diagonal, then the same positioning algorithms used for TOA or TDOA can be used to obtain location. The main challenge of using the received signal phase method is that it requires a line of sight for the signal path; otherwise, it will cause many errors. Combining the signal phase method with either TOA, TDOA, or RSS will improve the location's accuracy.

Time of arrival(TOA), the time is taken by the signal from the transmitter to the receiver, is measured, and it is directly proportional to the distance. In order to obtain the range estimate, the time taken is multiplied by the signal speed to obtain the distance. Using TOA measurements requires at least signals from three reference points, the range estimates represented in circles from each of the reference points are combined, and their intersection is the estimated position, two reference points will provide the location, but a third or even a fourth one would be used to reduce the ambiguity. The need for several reference points causes the rise of the problem of ensuring the three transmitters are in synchrony. For indoor measurements, the distances will be very short, so it requires very high precision. Another requirement is labeling the timestamp in the transmitted signal such that the measuring unit can discern the distance it has taken to travel.

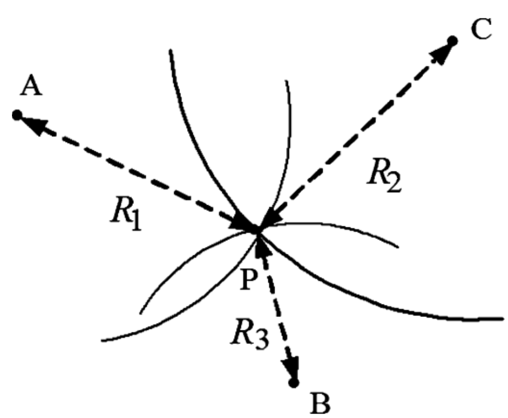


Figure 6:Positioning based on TOA/RTOF (Yim, 2015)

Time difference of arrival (TDOA), similar to time of arrival, uses the time taken to travel from the transmitter to the receiver to obtain distances. At times, it is not possible to determine the time at which the signal was transmitted from the transmitter; therefore, the difference in arrival time at the different measuring units is used to provide the distance. For TDOA, only the receivers are required to be in synchronization since the transmitters' time is not required; for each TDOA measurement, the transmitter should be on a hyperboloid that is at a constant range difference between the measuring units. The location is obtained from the intersection of two hyperbolas for the three measuring units.

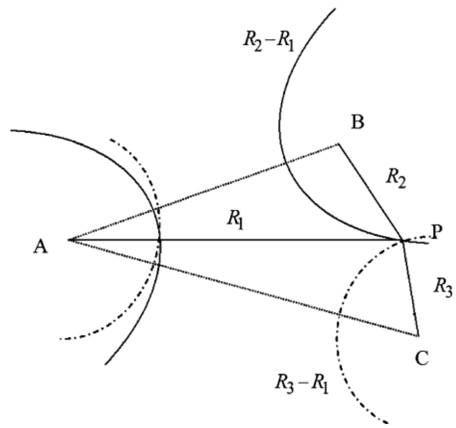


Figure 7:Positioning based on TDOA (Yim, 2015).

2.3.2 Angulation

Angulation is the other technique in triangulation. It estimates location using angle direction lines. Two angles are measured from two known reference points, and the intersection of the pair of angle direction lines can be used for 2D positioning. For 3D positioning, a third reference point would be used. The multipath effect and shadowing in the indoor environment limit the high accuracy requirement needed to measure the angles. In the case of a mobile device, the further the distance from the measuring unit, the less accurate the location estimate.

2.3.3 Scene analysis

This method obtains the location estimate using an algorithm that collects the features of a scene known as fingerprints and matches them with an online measurement with the closest a *priori* location fingerprints. Location fingerprinting is in two stages, the offline stage and the online stage. In the online stage it involves using the signal strength of the signal being observed and signal strength information collected previously to estimate location. In the offline stage, the measuring units' signal strength is collected during a site survey and used to obtain location estimates. Signal strength in the indoor environment is affected by reflection, diffraction, or scattering of the signal. The algorithms used in location fingerprinting include support vector machine (SVM), k-nearest neighbor (kNN), neural networks, and smallest M-vertex polygon (SMP).

2.3.4 Proximity

This algorithm relies on a grid of antennas to provide a relative location. The dense grid is from antennas of known positions; when a mobile object is detected by one of the antennas, it is considered to be collocated with it; if it is detected by more than one antenna, it is considered to be collocated with the antenna that receives the strongest signal. Systems using radio frequency, infrared radiation, and cell identification are mainly based on these algorithms. The advantage of using this method is that all mobile handsets support cell identification, and it is a simple method to implement over different physical media.

2.4 Research gaps

The rapid development of Wi-Fi-capable mobile devices and the wide availability of Wi-Fi network infrastructure have promoted several pieces of research on providing indoor localization by using Wi-Fi technology. However, instability of the Wi-Fi signal propagation in indoor environments introduces errors in the localization process. Therefore, a simple Wi-Fi localization approach like triangulation cannot cover the demands of practical applications in indoor environments, hence adopting the fingerprint method. Despite the many advantages, the fingerprint method has its limitations in terms of the signal strength; the received signal strength relies heavily on the existing environment, the smart phone's antenna, and the user's position. (Dari, 2018).This heavily affects the accuracy of the fingerprinting approach since it is difficult to obtain an accuracy within 2 meters for a practical application. Researchers have developed algorithms that can obtain good accuracy within the two meters however they end up taking too much time and require a lot of calculation which brings in another limitation(Ma et al., 2015).The expansion of the positioning environment and increased demand of fingerprint data similarly results in labor intensive and time consuming data collection therefore there is need for quicker and easier ways of capturing the data (Xia et al., 2017).

3. Methodology

3.1 Study area

The study area is the engineering laboratory building (ELB) located in Jomo Kenyatta University of Agriculture and Technology. The diversity, complexity, and number of buildings in universities make them a significant beneficiary and large target of indoor positioning technology (Abhilash & Asha, 2015). The indoor positioning system provides fast and accurate navigation within the buildings for the mobile user by identifying their current location, target location, and the detail of how to arrive at their destination.

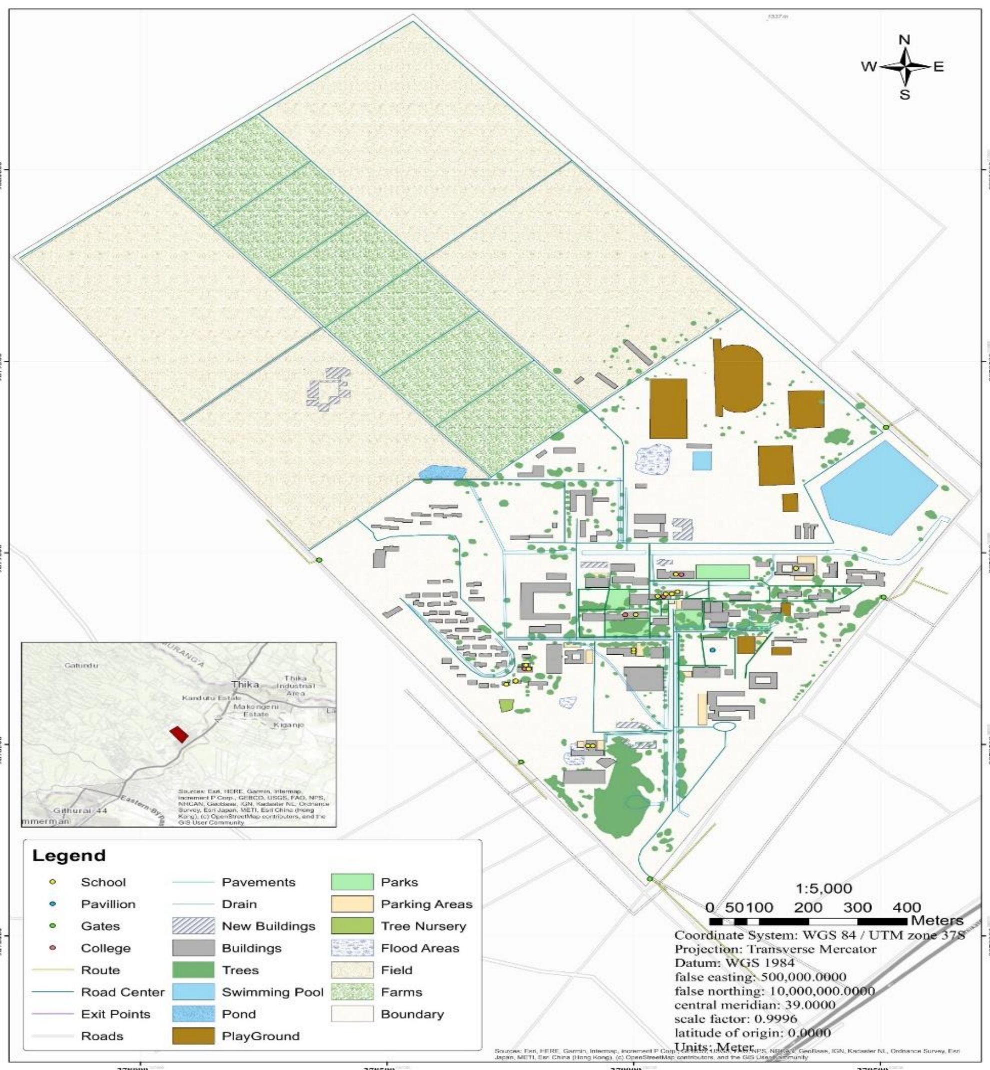


Figure 8: A map of Jomo Kenyatta University

3.2 Data

The primary data collection method was conducted through fieldwork; it involved collecting three sets of data. The first set was the floor plan data; this was the measurement of the building's dimension per floor to generate the building's floor plans. The second data set was from the mobile phone's accelerometer that was captured and displayed on the phone in the x, y, and z coordinates. This data represents the acceleration force in m/s^2 along each axis relative to the world’s reference frame. The final data set was obtained from the phone's gyroscope that was also in x, y, and z coordinates. This represents the rate of rotation in rad/s on each axis relative to the world’s reference frame. The update rate was set to default by the sensor_delay_normal method with an additional delay of 16 milliseconds using the thread_sleep method. Both data sets were returned in float array values.

3.3 Methods

From the main objectives of the study, the following resources were needed to achieve the objectives. They can be divided into hardware and software requirements.

Hardware requirements

A smartphone with an Android operating system that supports a minimum SDK of Android 4.1(Jelly Bean) and has a RAM of at least 2GB is the minimum requirement. The hardware specifications for the smartphone used for this study are listed below.

Name	**Information**
Model	Galaxy A50
Operating system	Android 10 with One UI 2.0
Screen resolution	2340 × 1080
RAM	4GB
CPU	Quad-Core ARM cortex A-53
CPU speed	1.7Ghz
GPU	Mail-G72 MP3

Table 2: Hardware Requirements

Software requirements

Name	Information
Test on Operating System	Windows 10
Drawing Software	ArchiCAD 22
Mobile Application Development tool	Android studio 4.0
Language	Java
Java Version	JDK 8

Table 3: Software Requirements

3.4 Process

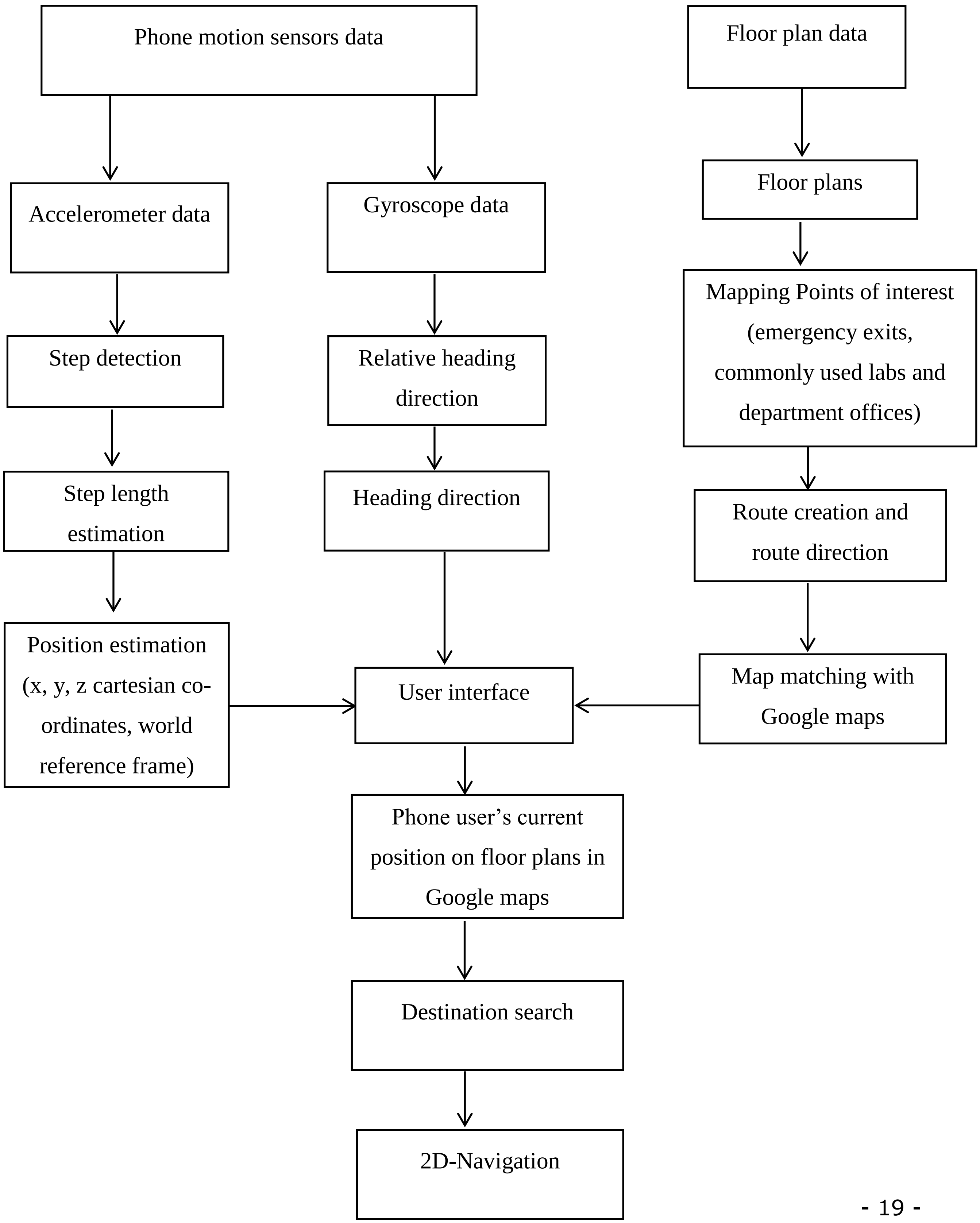

Phone motion sensors data
Floor plan data
Accelerometer data
Gyroscope data
Floor plans
Mapping Points of interest (emergency exits, commonly used labs and department offices)
Step detection
Relative heading direction
Step length estimation
Heading direction
Route creation and route direction
Position estimation (x, y, z cartesian co-ordinates, world reference frame)
User interface
Map matching with Google maps
Phone user's current position on floor plans in Google maps
Destination search
2D-Navigation

Figure 9: Flowchart of methodology

Floor data was collected by measuring the building's dimension using a steel tape of 50metres. A rough sketch was done using AutoCAD 2007 software, but further improvements were made using the ArchiCAD software.

The floor plan data was later added to Google maps using the mapwize studio platform. Points of interest were added at this stage, as well as the route direction. This allowed the engineering lab building floors to be aligned, a number of points of interest and route directions to be displayed on Google maps.

For the phone motion sensor, the first sensor to be used was the accelerometer. The data was collected using code written in Java in android studio. This displayed the phone user's motion in x, y, and z depending on their movement.

The second sensor was the gyroscope; the data was also collected using Java code written in android studio. It displayed the gyroscope values in x, y, and z to represent the phone user's orientation.

The mobile application was developed in android studio, the user interface contains the application's start page, and the second activity displays the sensors supported by the phone. The third activity contains the destination search bar, the floor plans matched on Google maps, the user's position, and their heading direction.

3.5 Methodological analysis

From the accelerometer data, the following were calculated; the acceleration magnitude (a), the step length (L), the average acceleration of the walking step and the estimated error of the step length (E)**.**

Acceleration magnitude *(a)* was calculated as:

$$a = \sqrt{{a_x}^2 + {a_y}^2 + {a_z}^2} - \mathrm{g}$$

Where g is the earth's gravitational acceleration, and it is equal to 9.8m/s^2.

Step length L was calculated using the acceleration magnitude and a personalized parameter:

$$L = K\left(\sqrt[4]{acc_{max} - acc_{min}}\right)$$

The average acceleration of the walking step was calculated using the step length:

$$L = \sqrt[3]{\frac{\sum_{i=1}^{n} |ai|}{N}}$$

Where N is the total number of step samples collected, ai is the acceleration measured in a single step, and K is the constant for unit conversion.

The constant rotation of the mobile phone makes it increasingly difficult to calculate an individual step length in real-time. Therefore, there is a need for error calculation. It is calculated as follows:

$$E = \frac{1}{\sqrt{ax^2 + ay^2 + az^2} - g}$$

The distance of the steps can be used in conjunction with the heading direction to calculate the user's position using the following formula:

$$S_{U,K} = \begin{bmatrix} S_{E,k} \\ S_{N,k} \end{bmatrix} = \begin{bmatrix} S_{E,k-1+l_k}.\sin 2\pi\theta_k \\ S_{N,k-1+l_k}.\cos 2\pi\theta_k \end{bmatrix}$$

Where S_E and S_N represent the user's current position outside and θ the angle around which the device has rotated along an axis.

Data from the gyroscope can be used to determine the user's heading direction using the pitch, azimuth, and roll. It is determined as follows:

$$Direction = \begin{matrix} N, if\ 315 < Azimuth \leq 45 \\ E, if\ 45 < Azimuth \leq 135 \\ S, if\ 135 < Azimuth \leq 225 \end{matrix}$$

4. Results

4.1 Floor plans

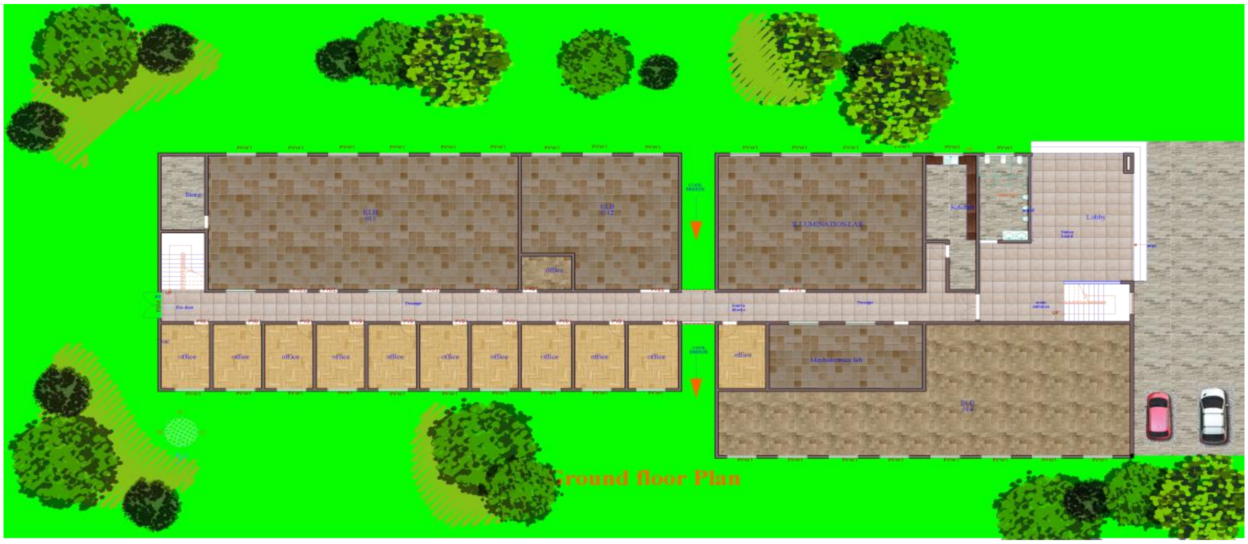


Figure 10: ELB ground floor plan showing all the rooms, offices and laboratories on ground floor

Figure 11: ELB first-floor plan showing all the rooms, offices and laboratories

Figure 12: ELB second floor plan showing all the rooms, offices and laboratories

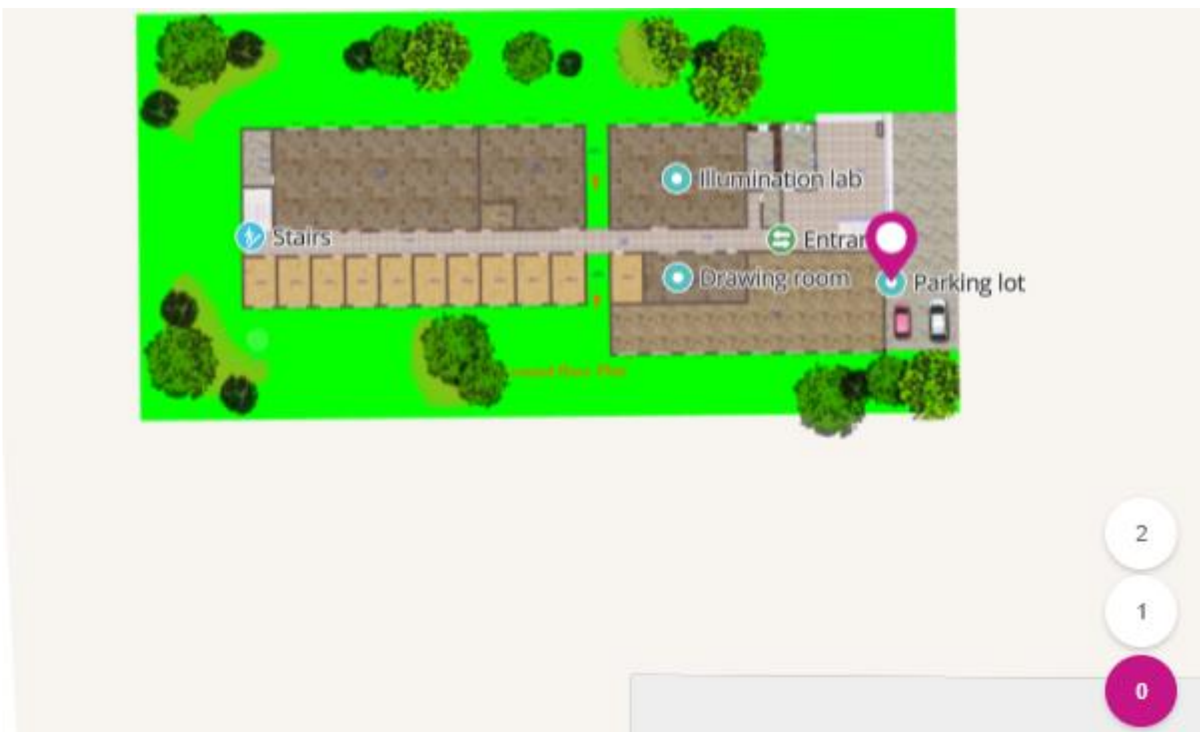


Figure 13: Ground floor plan with points of interest such as the main entrance, the illumination lab, drawing room and stairs

Figure 14: First floor plan with points of interest showing the entrance, the dean's office, Main lab ELB112, GEGIS department office and fire exit stairs

Figure 15: Second floor plan with points of interest showing the entrance, JICA offices and the ELB214 laboratory

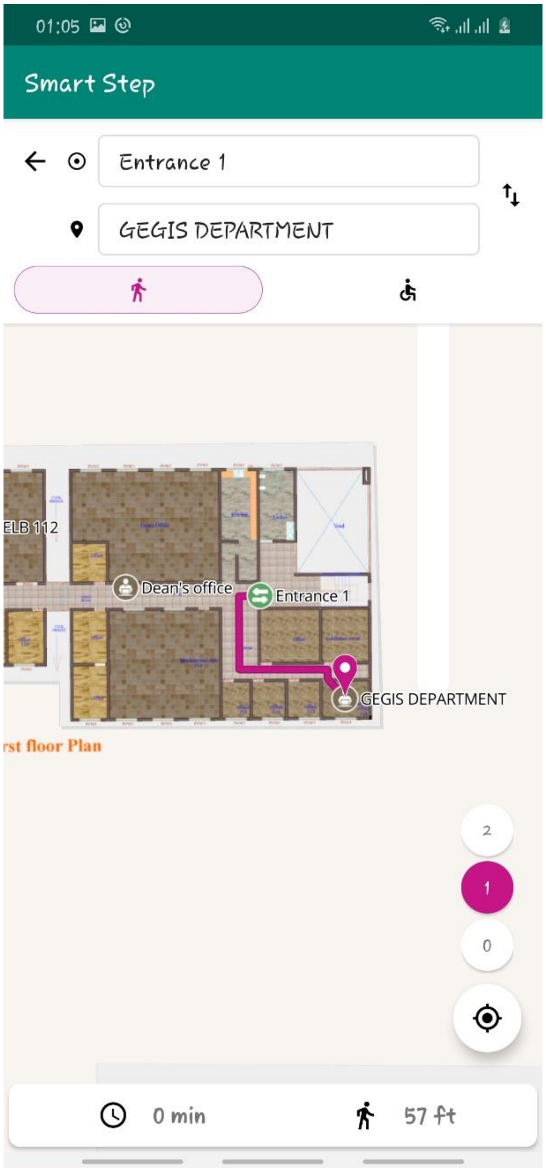


Figure 17: Floor plan with route direction from the first floor entrance to the GEGIS department

Figure 16: Floor plan with route direction from ground floor entrance to drawing room

4.2 Application's user interface

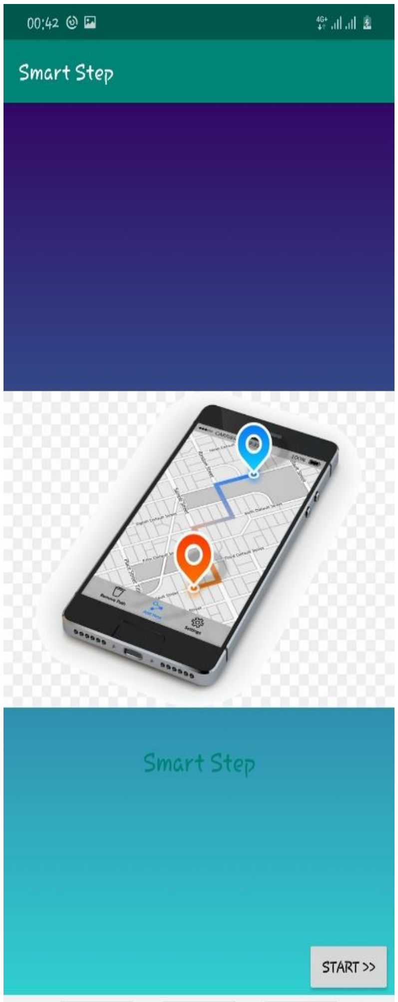


Figure 18: First activity page containing the start button

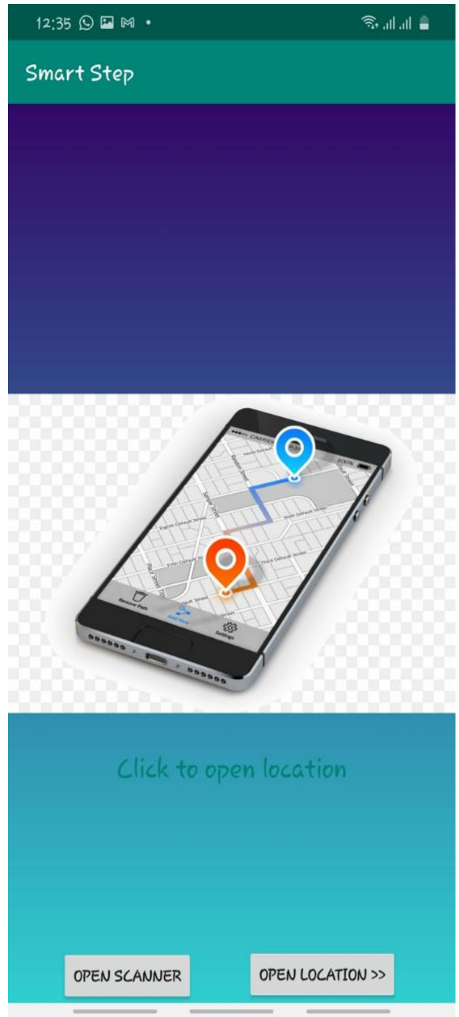


Figure 19: Second activity page with a button to open the scanner and a button to open the location activity page

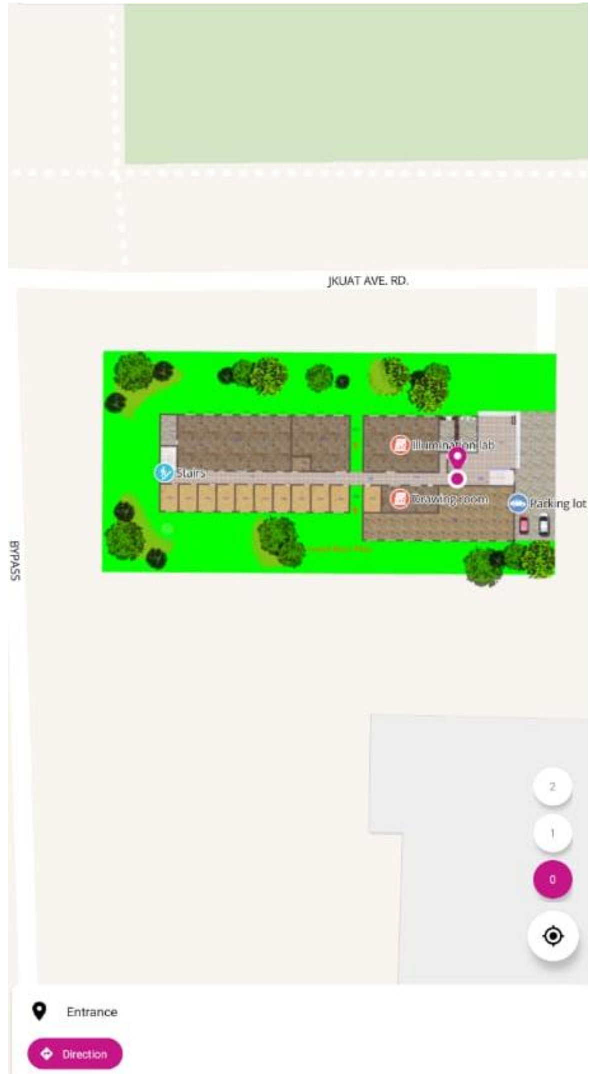


Figure 21: Location and Navigation activity page showing the global map

Figure 20: Location and Navigation activity page showing floor plan matched with the global map

Figure 23: Actual user position at the entrance and direction to the drawing room on ground floor

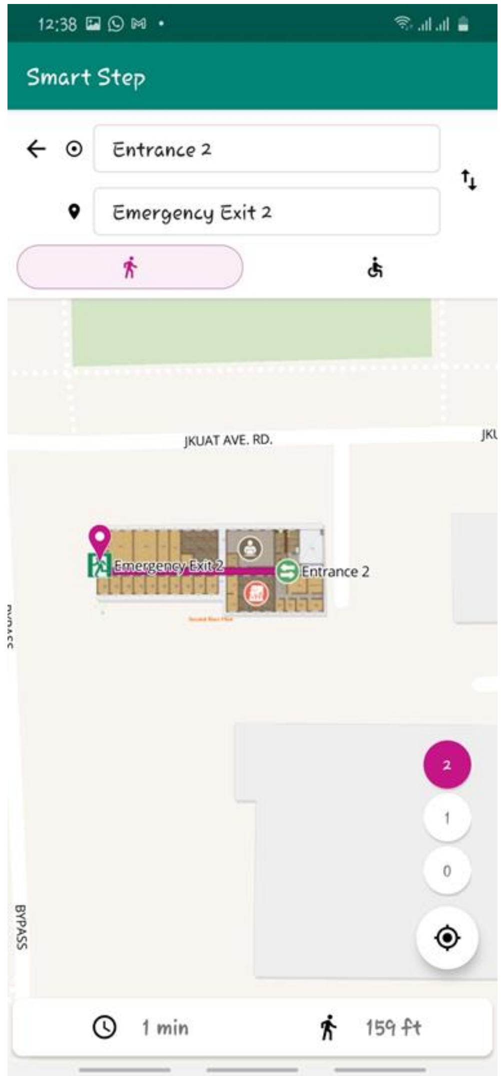


Figure 22: User position and direction to emergency exit stairs on second floor

5. Discussion

The results obtained from the first objective were the floor plans. A map has to be available for any form of positioning or navigation to take place, and it serves as the base for any navigation system. In the case of indoor positioning, the map is the building's floor plan; therefore, with the creation and availability of the floor plans, it is now possible to create an efficient navigation system. The map shows the various points of interest that will be included in the system. The target building was the Engineering Laboratory Building one of the buildings in JKUAT. It is the building commonly used by engineering students, it contains the dean’s office, department offices, numerous lecturers’ offices, the JICA office and the main laboratories.

For the points of interests on ground floor they included the commonly used laboratories, the drawing room and the main emergency exit. For the first floor it included the dean’s office for the school of Civil engineering, the GEGIS department, the main laboratories and stairs to the second floor. For the second floor, it shows the Mechanical Engineering department, the JICA office, main laboratory and the emergency exit stairs. The map allows the creation of routes and adding of directions in the system whereby for each floor it provided the route and direction to the emergency exit and stairs. It also displayed the route and direction to other points of interests like the department offices. The floor plan will show the user's current position in the building and their movement as well. These functionalities provide a seamless and effortless navigation experience for anyone using the system.

The information extracted from the accelerometer in XYZ shows the acceleration force in m/s^2 along the x, y and z axis. The gyroscopes control the platform's attitude therefore controlling the directions in which the accelerometers lie. Gyroscopes measure the mobile device's rotation speed in the earth's reference frame, but it will be expressed in the mobile device's frame. The gyroscope's three readings represent the Gyro roll, pitch, and yaw unit and should be in radians/second.

For the sensor data from both sensors, the information was obtained using code in Java with classes such as the sensor manager, sensor event listener class when a sensor event occurred, and the registered listener registering a listener. The methods used include getSystemServices that permitted to use of the sensor, getDefaultSensor that specified the type of sensor, onAccuracyChanged, and OnSensorChanged when there was a change in the sensor activity. Since the accelerations are continuously sensed to save on processing, the average delay method was used and the thread's addition. Sleep method set to 16 milliseconds so as to avoid checking every time the sensor is moved.

For the location and navigation activity code was written in Java to obtain the global estimation in the global frame and the Cartesian estimation. The methods used include setGlobalPosition that assigns the user's position in the global frame, setGlobalPositionAndHeading that assigns the user's position and heading, and the setGlobalHeading that assigns the user's heading in the global frame. For the change in the cartesian estimation, the setCartesianHeading methods assign the user's heading in the cartesian space, and the setCartesianPosition that assigns the users cartesian position to the position(x, y) in cartesian. The heading and heading accuracy are in radians, with heading expressed in a 0-2π frame increasing in a clockwise direction.

The application was tested in the engineering laboratory building (ELB); once the phone user was in the building, they could see their position within the building whether in a specific floor, room or corridor. As they moved inside the building, they could also track their movement and it was found that their movement on the ground matched with what was represented on the mobile application. The route direction allowed the user to search specific destinations and get directions on how to get there based on their current position.

6. Conclusion

This study shows that it is possible to develop an indoor positioning system using a smartphone and indoor maps to navigate an indoor environment without the need for additional hardware in the building. This has been achieved by developing a mobile application that provides the user with their accurate indoor position based on the floor plans on the outdoor map and displays their movement within the building.

The floor plans were successfully created and added to serve as the indoor maps to be used for navigation and positioning. The floor plans included points of interest that marked specific destinations and provided direction from one room to another within the building. The smartphone's built-in accelerometer provided the user's position and the gyroscope sensor provided the heading direction, which resulted in high accuracy in positioning and navigation.

The mobile application can be successfully used for navigation in complex and new buildings reducing the risk of getting lost or wasting time while looking for directions. It can also be used by the physically impaired to easily locate routes that have been specifically constructed to fit their needs. For buildings containing facilities fitted with sensors it can be used for facility management and asset tracking. The requirement of regularly updated floor plans for effective use of the system is an advantage to the building managers in building maintenance.

With inertial sensors as the indoor positioning technology used for developing the system, it can be concluded that it is an inexpensive system that uses readily available sensors. Additionally, it does not require extensive personnel training, and it is easy to maintain. For future works the system can further be developed to provide the same services for the visually impaired.

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