G405

Android Based Indoor Navigation Application using Earth's Magnetic Field Pattern

Case Study: UNIVERSITAS MULTIMEDIA NUSANTARA

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***Abstract*—An indoor navigation application can be built by utilizing the pattern of Earth's magnetic field which is unique at each location. In previous research, users have to record magnetic values all the way inside the building site before the application can be used. By utilizing built-in magnetometer sensors, magnetic values on the X and Y axis that captured by the sensor will be stored in a database and used as a reference point. This research uses the fingerprinting method for creating the magnetic database. There are two main phases in the research process, the first phase is to create magnetic field map database and the second is creating Android application for positioning. This research implements two magnetic data comparison functions, which are random function and first position function. The result shows that the maximum error position value is 116.54 meter for random function. While first position function returns a smaller number, which is 18.83 meters. It can be concluded that indoor navigation with magnetic database yield better accuracy compared to indoor navigation using GPS. This approach can become reliable solution if there are no communication channels to convey the message or to triangulate the position in emergency situation.**

Keywords—earth magnetic field, magnetometer, navigation, mobile, fingerprinting method

I. INTRODUCTION

People always say that they find it difficult to know their own position or looking for a location when they enter a new building. A building plan along with general information on each floor is unable to provide the position in real-time. This position information is very beneficial especially in emergency situation. However, this problem can be solved with the use of navigation applications in mobile devices (smart phones), which has been commonly used in everyday life. In such condition we cannot only rely on the position data which need communication channels to convey the message or to triangulate the position.

Many prototypes of indoor navigation have been developed in recent years. However, most of the prototypes require an external device. One of the devices that developed for the navigation system in the building utilizes the value of the Earth's magnetic field as a reference [1].

Using the magnetometer which has now become standard sensor in recent smart phones, it is possible to develop an indoor navigation application without external devices. Magnetometer is a sensor that can be used to measure the strength and show the direction of the Earth's magnetic field. The use of the magnetometer was based on case studies conducted by IndoorAtlas [1]. This study was conducted to create The Android application for indoor positioning using the Earth's magnetic field on the X, Y, and Z axis based on a magnetic field map that has been stored in the magnetic field map database.

II. MAGNETIC FIELD

A. Earth's Magnetic Field In Cartesian coordinates

At any location, the Earth's magnetic field can be represented as a three dimensional vector. Using a Cartesian coordinate system, the X-axis is the angle towards the north geographicalpole, Y-axis is east geographical pole and Z-axis pointing down. Declination angle (*D*) measures the angle between the Earth's geographic north pole and magnetic north pole [2].

In addition, there are deviations toward Earth's geographic and magnetic compass, the needle itself also had positions that are not flat. Horizontal direction deviation was due to the magnetic lines of force is not parallel to the surface of the earth (in horizontal plane). As a result, the compass needle that points toward the north pole, will deviate either upward or downward to the earth's surface. The deviations in the compass needle will form an angle to the plane surface of the Earth. The angle formed by the compass needle's north pole with a flat surface is called the angle of inclination *I*.

Declination angle (*D*) can be obtained by

$$tanD = Y/X, \quad (1)$$

thus, the total magnetic field strength (*F*) is,

$$F = \sqrt{X^2 + Y^2 + Z^2} \quad (2)$$

And the inclination angle (*I*)

$$\tan I = Z/\sqrt{X^2 + Y^2} = Z / H \quad (3)$$

where *H* is the magnetic force on the horizontal field in X,Y and Z axis[2].

B. Tri-axial Magnetometer

Magnetometer is an instrument for measuring the strength of a magnetic object. Embedded magnetometers in smartphones can measure the strength of Earth's magnetic field through a three different direction known as tri-axial magnetometer [3]. T*ri-axial* magnetometer sensor on a *smartphone* represented by X, Y and Z axis that prescribed by the right hand rule in accordance with the Lorentz force. X is the horizontal plane and points to the right, Y is on the vertical plane and points to the front and Z is pointing up, which can be described in the figure 1.

According to the *develeoper.android.com* as an official website of Android application development,the magnetic field sensor on Android will measure the magnetic force on tri-axis way. The sensor direction does not change even if the user rotating the screen orientation.

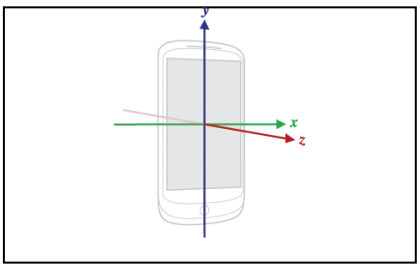

Figure 1. Smartphone sensor direction[3].

The amount of magnetic force in the direction to X, Y and Z can be used for the calculation of the magnetic field strength *F* (total) [2], where

$$F = ||Bx + By + Bz|| \quad (4)$$

in x, y and z axis.

C. Magnetic Field Fingerprinting Map

A methodology called "fingerprinting" is widely used where signal propagation is unpredictable, this method allows the system to use a lot of samples on a wide area [4]. The method is to put some value (eg: earth magnetic value) into the database and mapping it on a map. Fingerprinting method for localization is called scene analysis, one of its application is the mapping of signal strength on WiFi network in a building [5].

Fingerpinting carried out in two phases, the offline and online phase. In offline phase, the magnetic data at each location will be collected into a database and mapping it according to the earth magnetic strength's value. The X, Y and Z value that stored in the database are obtained from tri-axial magnetometer sensor. In the online phase, the magnetic field values obtained by the device user will be compared with the existing data in the magnetic database [6].

The placement of device will not affect the Earth's magnetic values, but it actually only affect the recorded values. For this study the device is placed at the bottom of the chest.This posisition give a better results compared to the wrists, legs and shoulders with the average value of the magnetic difference reaches 20% [7].

Magnetometer sensor which is used for measure the earth magnetic field is also be affected by static magnetic field. The database of magnetic field should be updated if some environment on a building has changed drastically, by providing new database record near the affected environment.

III. SATELITE BASED POSITIONING

A. GPS

GPS stands for "Global Positioning System". GPS is a satellite navigation system used todetermine ground position and velocity (location, speed, and direction). GPS was first developed by the U.S. Department of Defense which is used for military purposes. In general, the use of GPS for outdoor navigation activities have 50 to 150 meters accuracy rate when using cell tower triangulation, while the use of GPS satellite sensors directly provide a higher level of accuracy, which is able to achieve accuracy of 1 to 10 meters [8] .

B. Positioning in GPS

GPS works by collecting data obtained from each satellite signal continuously, the data are in the form of information about when the signals are transmitted using atomic clocks that located on satellites and which satellites that sent the data. Afterwards, data are processed in GPS receiver to determine the position of the distance of a sateite signal sender and the distance between each near satellites [9].

A coordinate knows as waypoint (latitude and longitude) will be obtained from the sampling of its locations. Then, by applying satellite trilateration method, the GPS will counts the approximate position of the receiver.

Trilateration is a method for finding a relative position using a circular geometry. The triangulation or trilateration works by comparing the position of a satellite receiver with other satellites, each satellite has a different distance to the receiver. So, the point of intersection between the three satellites is estimated to be a receiver position [10].

If there are not enough satellites, the trilateration method can not be done. GPS will use a method known as absolute or point positioning, where a position will be determined using only one satellite. The accuracy of the receiver position is not accurate and is intended only for navigation.

IV. MAGNETIC FIELD PATTERN POSITIONING

Refering to a fingerprinting method, which is divided into two phases, storing the magnetic value into a database (offline phase) and data comparison (online phase). This study implemented two applications, the first application is "GeoRecorder" that used to capture the value of the Earth's magnetic field from a location. This application read the magnetic value using magnetometer sensor obtained by a device from a location and stor into a text file.

The second application is "Emone" (*Earth magnetic observed navigation evince*) that used by the user to inform their position. This application use OSMdroid library for showing the building map and the navigation process, also the navigational menu like zoom and scroll map.

A. GeoRecorder

GeoRecorder system is initialized by registering the magnetometer sensor on the device. If there is no magnetometer sensor, then the application will display error message information and the application is forced to stop. Besides a magnetometer sensor, the system also uses GPS to get the latitude and longitude values that used as the reference point during the map binding process. If the coordinates obtained using GPS are inaccurate inside a building, then this coordinates is only being used as a check values where the reference points are generated from the position reference in outer position of the building where the value of GPS satellites positioning have adequate precision (sufficient PDOP values).

After the sensors have been registered, the application will record the magnetic values along with the coordinates in one position per second and calculates the average of the magnetic values that obtained. It is used to minimize the possibility of error when the magnetic sensor captures a value that is skewed from the actual value. This because of the value that read by a magnetic sensor can be varied and changes so fast. Finally, the system will create a new text file for data placeholders. The system will continue to repeat until the application is stopped and sufficient data is generated for generating the magnetic database map. The flow chart of this application can be seen in figure 2.

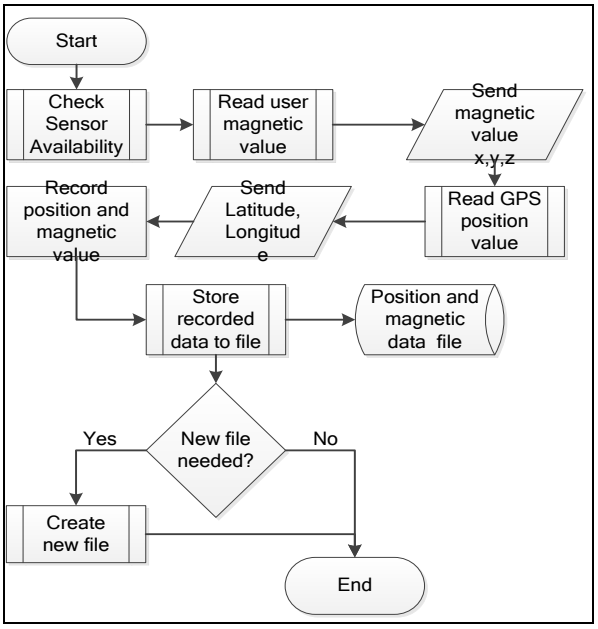

Figure 2. Flow Chart of theGeoRecorder Application.

B. Emone

The functions for sensor checking system and magnetic reader system used on the Emone application are adopted from GeoRecorder application. Slight modification is needed because Emone does not require a data storage menu. Application initialized by loading a map of a building or specific area and then continued to load the entire magnetic database for positioning. The magnetic database is then converted into arrays to speed up the positioning process. Furthermore, the system will prompt the user to perform calibration at predetermined points shown on the map. Calibration process is used to correct the deviation of magnetic value acquired by different devices other than the device used to generate the reference magnetic data values stored in a database.

Calibration process produces a constant calibration values used to reduce or add value of magnetic sensors that obtained by user. The system will perform comparison of magnetic values which are read by the sensor device every second. Such data will be compared with magnetic values database that has been deposited into the array to determine the user location. Finally, the system will show the user's position on a map based on latitude and longitude obtained from the previous process. The flow chart of this application can be seen in figure 3.

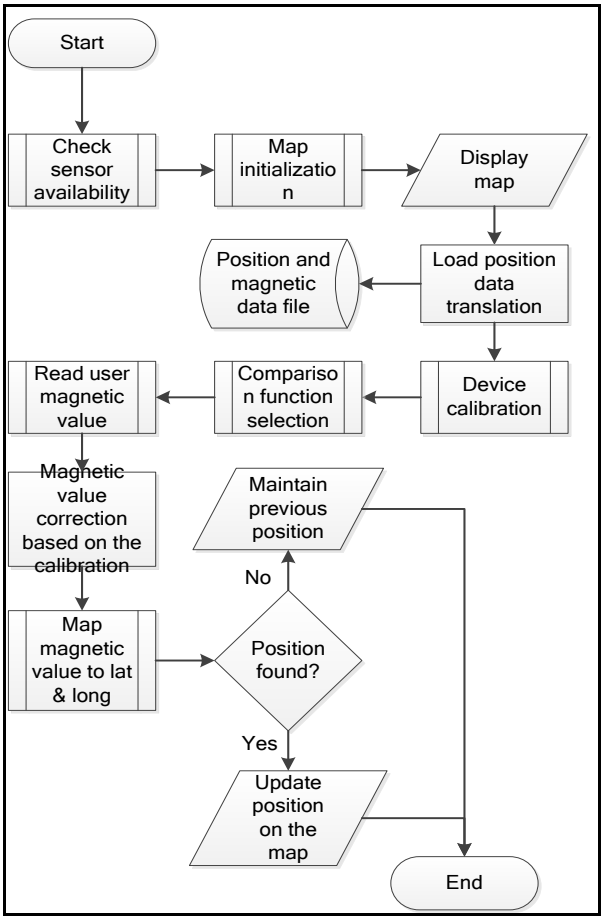

Figure 3. Flow Chart of theEmone Application.

C. *Collecting and Mapping Earth's Magnetic Field*

Magnetic field data collection is collected in two directions, by a vertical and a horizontal directions referring to a map layout of buildings that is used in this application. The retrieval is done using a device that has been equipped with GeoRecorder applications. Magnetic data were taken with the certain value of distance on each single floor. Here are the steps for taking a magnetic value at a location.

1) Device placed on a tripod with a box that can help minimizethe magnetic interference from outside
2) Positioning device at 105 cm above the ground, or positioning at abdominal of user
3) The user place the device in the middle of the floor and pressing the record button on the application
4) Application will store the magnetic value and write it into a text.

Once the magnetic data collected into a text file, then the value will be mapped to form the magnetic latitude and longitude position using the reference of latitude and longitude position information on MapInfo. Using the maps published in MapInfo, we can bind the value of the magnetic placement with placement assistance point. Finally, the entire text file that contains the value of the magnetic field and its position will be imported into a database using SQLite Manager Application. The results of magnetic data on building floor plan are shown in figure 4.

Figure 4. Magnetic sensor placement during data gathering on building floor plan.

V. MAGNETIC COMPARISON FUNCTION MAPPING

In this study, we use two comparison functions for comparing the magnetic values obtained by user with the magnetic field map database that has been created before. The comparison process produces a coordinate that will be used for determining the user position.

A. *Random Function*

Random function will compare the value of the magnetic field that obtained by the user with all the magnetic data contained in the database. These are the procedures that performed on the random function:

1) Comparing the X-axis magnetic field value in the database with the X-axis obtained by user
2) Accommodate the sequence (rowid) from the value on the X-axis between the same user and the database
3) Increase or decrease the range with difference of 0.1 to obtain the same magnetic values between users and database
4) Comparing the Y-axis magnetic values on database with user based on sequence (rowid) that obtained before
5) If the difference in the value of the Y-axis is not greater than or equal to the limit, then the comparing process is successful.

B. *First Position Function*

First position function will find a position of the point of departure from the previous position, at the first, it will use the latitude and longitude values at the starting point of calibration position. Then, the system will search for magnetic values in the database which are located near the area, and discard (filter) the magnetic values which have much difference with the user magnetic value. These are the procedures that performed on the first position function:

1) Check the current user coordinate location and find the magnetic value on X-axis and Y-axis in the database that was near the area

2) Comparing the value of magnetic X-axis and Y-axis obtained by user with database where area has been limited
3) Widen the comparison are by adding the value of the latitude and longitude of 0.00001 if there is no magnetic values are equal or adjacent.

VI. RESULT AND DISCUSSION

This study performed using three different devices for testing purpose, Xperia X10 mini, Galaxy Chat, and Nexian Journey. All those devices are used to see how much distance errors obtained by each device. After each calibration device and conducted 10 trials to the specified point. Table I shows the result of the error for the random function and the results of the error for first position function. Figure 5 shows the error rate in units of meters on each device and comparison functions are used.

The results of a series of trials that have been done show that:

1) Looking at the error position ratio obtained from the three different devices, there is no significant difference in error distance between the device with other devices. This is due to the differences of magnetic value that read by each sensor device has been corrected by a calibration process.
2) There is relatively high value of error obtained on random functions, which reached 116.54 meters. That is because there are several magnetic values identical at different coordinates. The algorithms used in the random function does not compare the new coordinates that obtained with the previous position coordinates, as implemented in the first position function algorithm. So that, algorithms on random function will display the position on the map if there is any value equal or close to the databases magnetic values obtained by the user.
3) Broadly speaking, the searching process and comparison functions are carried out by first position takes longer than random functions. It can be seen that the application will get some delay when updating the location at a time. This delays could become a problem when the user walks so fast and the position has not been updated.

TABLE I. ERROR COMPARISON RESULT

Device	**Random Function**		
	Max. Error (meter)	***Average Error (meter)***	***Std. Dev.***
Xperia X10 mini	116.2	27.1	30.14
Galaxy Chat	116.54	24.51	25.58
Nexian Journey	110.65	24.89	26.77
Device	**First Position Function**		
	Max. Error (meter)	***Average Error (meter)***	***Std. Dev.***
Xperia X10 mini	13.25	6.08	4.28
Galaxy Chat	17.64	7.45	4.05
Nexian Journey	18.83	6.61	3.43

4) Algorithms on random functions comparison focuses on the X-axis, while the algorithm on the function compares first position in both X and Y-axis to find the nearest position. This makes first position function is more accurate for get a new location and does not display the displacement distance is too far when compared with the random function.
5) From the test results, the value of magnetic influence on the Z-axis will be generated if the altitude of the device is not the same. In this research, users are not required to hold the device at a high position. Therefore, if the user holds the device in the same location with a different height, the Z value that obtained by sensor will always be different. Therefore, comparison using the Z-axis value were eliminated.

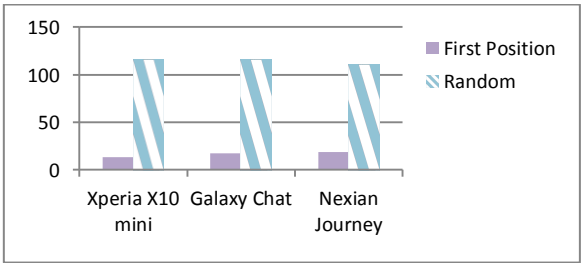

Figure 5. The maximum number of error between devices.

6) Errors or gaps can occur due to magnetic data comparison in the incomplete data-record. When the user is in a position other than horizontal and vertical position, the magnetic values that caught in such position will not match the value of the magnetic owned by the database. Therefore, to get a more accurate position of the user, the magnetic database should be created not only using the horizontal and vertical position only, but also with every axis.

VII. CONCLUSIONS

Earth's magnetic field can be used as a reference for navigation within a building. Magnetic field values obtained from the results of the study have a unique value and there is a pattern of sequential magnetic values at some point the location. This pattern makes first position function has an average error rate of 6.7 meters.

The use of magnetic database as a reference for acquire the user's position is potential to replace one's duty to

accommodate magnetic values. Despite the value of the maximum error at 18.83 meters, the magnetic database has been able to be used as a reference to determine the location of where the users with fairly accurate position. This position errors caused by the reading process on Earth's magnetic field value at a position besides vertical and horizontal directions, which is not stored inside the magnetic database that has been made.

The use of the earth's magnetic field as a navigation reference inside a building gives better results when it's compared with the GPS for navigation inside a building.

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