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Geomagnetic Fingerprint Maps for Indoor Positioning

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Abstract—Indoor positioning technology is becoming the hot spot of the current research. How to choose a suitable positioning scheme is particularly important. This paper focuses on the geomagnetic field, and geomagnetic fingerprint maps for indoor location. The methods of constructing geomagnetic fingerprint map are verified via experiments. Experimental results show that the accuracy of the scheme which uses the magnetic field strength values of special landmarks is not enough to constructing efficient geomagnetic fingerprint maps. The method of combining the magnetic field strength value with the path can not only solves the numerical difference caused by the microelectronic mechanical systems sensor effectively, but also has high positioning accuracy. At the same time, it is feasible to use the idea of group intelligence to construct a geomagnetic fingerprint map. We make the corresponding summary to the second scheme, which needs to be further optimized on the original basis so that it can be truly applied to real lives. This paper analyzes the information of the geomagnetic field, compares the schemes of constructing the geomagnetic fingerprint map via experiments, and promote the further development of geomagnetic field in indoor positioning technology.

keywords: Indoor positioning, Geomagnetic field, Fingerprint maps

I. INTRODUCTION

Location Based Service has brought great convenience to people's production and lives, and they have been widely used in engineering surveying, outbound navigation, rescue, agriculture and military fields. At present, the mature satellite positioning technology have the Global Positioning System(GPS), the Global Navigation Satellite System(GLONASS), the Galileo Satellite Navigation System(GSNS) and BeiDou Navigation System (BDS). With the rapid development of the wireless communications technology, Internet technology and the microelectronics technology, smart phones, wearable devices and other mobile terminals has been widely popular. At the same time, with the acceleration of urbanization process, people spend more than 80% in the room [1]. Therefore, people in the room also have a high demand for positioning.

Due to the severe attenuation of the satellite signal in the case of obstruction, the positioning accuracy of the high-rise buildings and the indoor environment is very low, and the indoor positioning and related service requirements can not be realized. Therefore, based on indoor positioning services has become the academic and business researches and development focuses [2]. Compared with outdoor positioning, indoor environment has a small range of activities, high density and high frequency of personnel activities. Therefore, the indoor environment requires higher accuracy than outdoor environments. At the same time, with the popularization of intelligent mobile terminals and the advantages of indoor environment, the deployment of positioning equipment has some advantages.

At present, there are many solutions for indoor positioning services, such as Wireless Fidelity (Wi-Fi) positioning, Radio Frequency Identification(RFID) positioning, Wireless Sensor Network (WSN) positioning, Bluetooth Low Energy(BLE) positioning and Ultra-wideband (UWB) positioning. Each scheme has its own unique characteristics. For example: Wi-Fi technology has a long communication distance, and it has a large area of signal coverage; the cost of the RFID tag is very low, and it can be deployed in a wide range; WSN can be implemented without the external network, the BLE technology is low energy consumption, and it does not require external power supply; UWB technology communication speed, positioning accuracy. But these programs require the deployment of equipment indoors.

For the above-mentioned positioning scheme, it can be divided into three-side matching [3] and pattern matching. The principle of the trilateral matching is to measure the distance or angle of the body to the signal source, and then use the geometric formula to calculate the specific position of the body. For example, time of arrival(TOA) algorithm, time difference of arrival(TDOA) algorithm, an algorithm based on the time of the signal flight (TOF) and the AOA algorithm. This method is generally used in cellular base stations, and wireless network technology can use this way to locate. However, we generally use pattern matching method to locate in indoor environments. This positioning method is store the fingerprint database by using the

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information of each point in the room. And then in the positioning phase, compared the information of the specific location and the information in the database to achieve the positioning function. Indoor positioning scheme mainly uses this method.

In order to better achieve indoor positioning, how to effectively build a fingerprint map has become the first indoor positioning technology difficulty. As the indoor environment changes, signal block, fingerprint map update is not timely and other issues will make the accuracy of indoor positioning significantly reduced. So how to build a high-precision and effective fingerprint map has become the focus of the indoor positioning technology research.

In the process of building a geomagnetic fingerprint map, we found that building a fingerprint map is a very complicated task. A key factor in achieving high-precision positioning is the selection of signal source. A good source will lay a good foundation for achieving high-precision positioning. And outdoor environment, indoor signal source is relatively complex, if using a single source location as the basis, it will have a great influence on the accuracy of positioning. If a single signal source is used as the basis for positioning, the positioning accuracy will be greatly affected. Finland's IndoorAtlas company developed a positioning of the software, relying on geomagnetic and Wi-Fi positioning signal source. This software can achieve high-precision indoor positioning needs. With the development of the study, the geomagnetic field has gradually come into the researchers' field of vision. Geomagnetic field is inherent in the natural resources of the earth. Although human beings cannot observe it directly, they can be detected by sensors. The current research hotspot is how to use the geomagnetic field to build a solution for indoor positioning, the most important of which is how to build geomagnetic fingerprint map.

The use of geomagnetic field to achieve the indoor positioning has the following advantages:

- The geomagnetic field is always existing. It is a natural and stable information on earth.
- The geomagnetic field does not rely on external energy. Using the geomagnetic field as the basis for indoor positioning is not dependent on the source of the device, especially if there is no power support.
- No additional equipment is needed. Compared to the Wi-Fi positioning scheme, the use of geomagnetic field positioning program does not need to set up any auxiliary equipment in the room.

The contribution of this paper is:

- This paper introduces the information contained in the geomagnetic field and the principle of using the geomagnetic field for indoor positioning.
- How to use geomagnetic field information in indoor environment to study the construction of fingerprint map.

In this paper, we have experimented with the existing methods of constructing fingerprint map by using geomagnetic field. We also present the feasibility analysis of constructing geomagnetic fingerprint maps under the current hardware base conditions.

The rest of this paper is organized as follows. In Section II, the geomagnetic positioning principle is briefly introduced. Section III describes the schemes of construct geomagnetic map in detail. And the experiment results are presented in this section too. Finally, Section IV concludes the paper and points out the future research direction.

II. GEOMAGNETIC POSITIONING PRINCIPLE

A. The geomagnetic field and Measure the information

From the ancient Sinan to today's smart phone's compass software, they all use the earth's magnetic field to find the direction. Studies [4] have shown that geomagnetic fields can be divided into nuclear field, crustal and partly from the magnetic fields such as magnetic storms. Of the geomagnetic data we measured, the nuclear field accounted for 95%. When the geomagnetic storm occurs, the field of the field changes little and fast. So, we can use the geomagnetic field as the source of the signal.

With the development of the micro-electromechanical systems, the technology of sensors such as gyroscopes, accelerometers and magnetometers have become more and more mature. Microcomputer electromagnetic force meter [5] can detect the magnetic induction in space, which is made of anisotropic magneto-resistance material. This kind of crystal structure of the alloy material is very sensitive to the external magnetic field; the strength of the magnetic field changes will lead to the anisotropic magneto-resistance of its own resistance value changes. In the absence of a magnetic field, the circuit output is zero, and in the presence of a magnetic field, the circuit outputs a tiny voltage ΔV. The magnitude of the magnetic field is determined by detecting ΔV. The earth's magnetic field in general case, however, only a weak 0.5 gauss, horn and a normal mobile phone in the location of the 2 cm would produce about 4 gausses magnetic field, a mobile phone motor position in 2 cm apart will produce about 6 gausses magnetic field, this characteristic makes to electronic equipment on the surface of the earth's magnetic field measurement are vulnerable to the interference of the electronic device itself. This feature makes the measurement of the Earth's magnetic field on the surface of an electronic device susceptible to interference from the electronic device itself. Therefore, before using the magnetometer we need to calibrate it, calculating the interference vector and then eliminating the interference.

B. Geomagnetic field contains information

Geomagnetic field can only give us directions in the outdoors, but can not provide necessary information for navigation. Building steel structure and indoor power equipment will affect the indoor magnetic field information. When using the concept of magnetic induction lines [6] to describe the magnetic field, we can use the direction and density of the lines. In Fig. 1， it represents the direction and intensity information of the magnetic field.

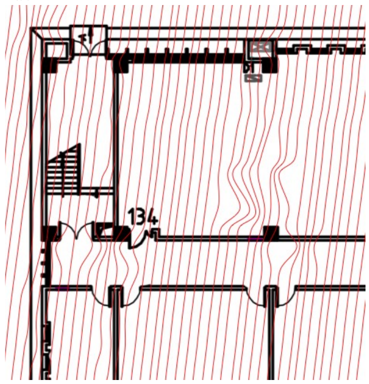

Figure 1. Indoor magnetic induction line diagram

Such geomagnetic fields are undoubtedly a natural source of information, with the advantages of natural, non-radiation and no external source. So, if you use it as a basis for positioning it will reduce a lot of costs. We need to fully study the magnetic field with the information before we use it to position. First of all, the smart phone sensor to obtain the data is three-axis information. The three axes of the mobile phone are as follows:

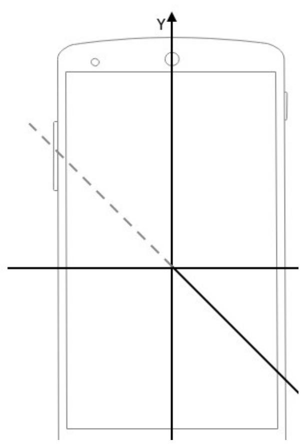

Figure 2. Android system coordinate system; when faced with smart phones, the vertical screen is the z-axis, along the screen to the left is the x-axis, along the screen up the y axis.

In such a coordinate system, the magnetic field information collected by the smartphone is represented by the data of the three axes. When we synthesize them, we can represent the rich information of the geomagnetic field. Fig. 3 shows the information of magnetic field. ***M*** is for the point of the magnetic induction line tangent, with the size and direction of the two properties. Its projection on the z-axis is called the vertical component Z. Its projection on the x-y plane is called the horizontal component ***H***, and the horizontal component ***H*** is obtained from the x, y component

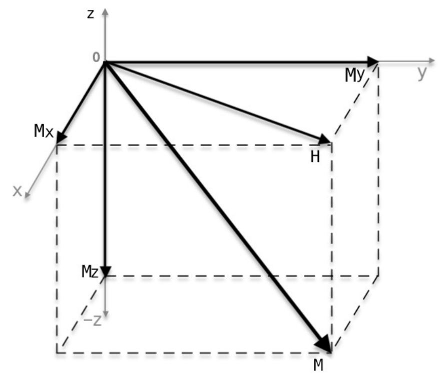

Figure 3. Information of magnetic field.

We know that the tangent of the magnetic induction line can represent the intensity and direction of the point. So, the space vector ***M*** has both the numerical size and the direction of the two attributes. Therefore, the magnetic field strength value can be expressed by the following formula:

$$M = \sqrt{M_x^2 + M_y^2 + M_z^2} \tag{1}$$

Where ***M*** is the total intensity of the geomagnetic field, $\boldsymbol{M_x}$, $\boldsymbol{M_y}$, $\boldsymbol{M_z}$ are the three-axis component data collected by the mobile magnetic force sensor.

Then we use the magnetic declination and magnetic dip angle to represent the direction of the magnetic field information. First, the horizontal component ***H*** of the magnetic field strength is:

$$H = \sqrt{M_x^2 + M_y^2} \tag{2}$$

Where $\boldsymbol{M_x}$ and $\boldsymbol{M_y}$ are the magnetic field strength values for the x and y axes of the smartphone.

Because we can not get the north direction of the earth through the smartphone sensor, we assumed that when the y axis is pointing in the north direction, the magnetic declination is the angle between the geomagnetic field and the north direction of the earth. The formula is:

$$D = \arctan\frac{M_x}{M_y} \tag{3}$$

Then the magnetic dip is the angle between the total intensity and the horizontal component. The formula is:

$$I = \arctan\frac{M_z}{H} \tag{4}$$

The geomagnetic field has the above seven information. And they are in the indoor environment has a greater difference. So, it can be used as a signal source for indoor positioning.

III. BUILD A FINGERPRINT MAP

A. *Using fingerprint map positioning*

In order to use geomagnetic information to locate, we mainly adopt the pattern matching method in the introduction. First, we need to build an off-line geomagnetic fingerprint map [7,8]. As it has been shown in Fig. 4, we first need to divide the indoor environment into a virtual grid, and then collect the geomagnetic information of each point in the grid and save it to the database. In addition, the indoor path can also be used to store the magnetic field information, with the information stored in these paths to build a geomagnetic fingerprint map. No matter how the information is processed, like cluster analysis [9], the last thing we need is a fingerprint database based on the indoor geomagnetic information. This completes the construction of the offline fingerprint map.

In the positioning phase, we match the information collected by the smartphone sensor with the fingerprint map database. For example, the Wi-Fi fingerprint map usually uses the KNN algorithm [10] to estimate the final position. Through a similar approach, we can achieve the purpose of positioning.

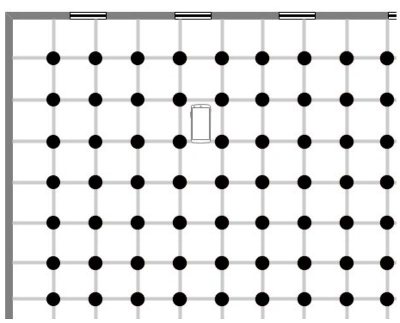

Figure 4. Schematic view of the pattern matching method.

B. *Construct geomagnetic fingerprints*

In order to verify the feasibility of building a geomagnetic fingerprint map better, we developed a test system with Android platform, and used the database table showing in Fig. 5 to store geomagnetic fingerprint information.

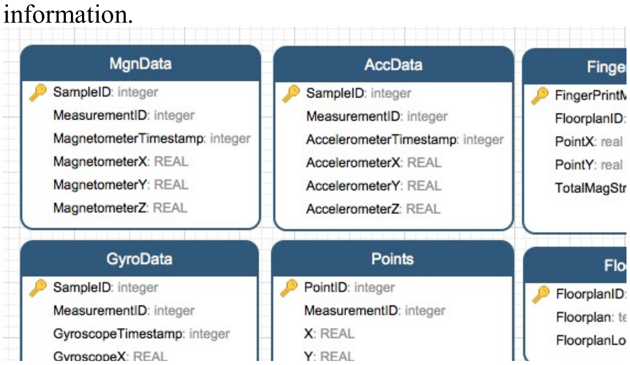

Figure 5. Data sheets for geomagnetic fingerprint storage.

The accelerometer and the gyroscope can record the path of the walk, and the magnetometer is used to obtain the strength of the geomagnetic field. We use the coordinates of the plan to match the total intensity of the way to build a geomagnetic fingerprint map.

In the second part, we have introduced the geomagnetic field, the information it contains and the working principles of the magnetometer. How to construct the geomagnetic fingerprint map by using this rich information has become the focus of our research. In the above work, we know that indoor magnetic field intensity is not evenly distributed, and it is stable. So, it's easy to think a fingerprint map based on the intensity of the different places in the room. However, in the actual measurement, we found that the total strength of the indoor geomagnetic measured by the Nexus 5 AK8963 electronic compass sensor is generally 40-60μT. Such a range of intensity changes is insufficient to provide the need for positioning. And we found that different types of smartphone sensors, calibration algorithms are not the same. Therefore, different models of smartphones to measure the same point of the magnetic field strength values will be different [11]. This difference also brings the difficulty of building our fingerprint map.

In order to build the geomagnetic fingerprint map better, we investigated the mainstream geomagnetic fingerprint map construction method, and developed the following experiment:

We chose the first floor of the computer science department of Nanjing post and telecommunications university as an experiment. The section of the subject building is shown in Fig. 6.

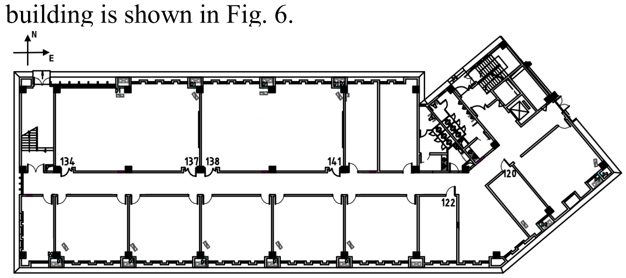

Figure 6. The plan of the subject building of school of computer science, Nanjing University of Posts and Telecommunications

1) *Using the special position of the abnormal magnetic field strength as a basis for positioning*

In the present study, one of the main ways to build a fingerprint map is to build the total intensity of the geomagnetic field in the indoor environment. We found that the intensity of the magnetic field will be significantly increased in some corners or walls. With this feature, Brandon Gozick, who proposed a method of using the special position of the indoor abnormal geomagnetic field strength values to establish fingerprint map in the paper [12]. In the paper, they did experiments with the Motorola droid and Nexus one in the University of Texas campus. They measured and recorded the magnetic field values near the column on campus. After collecting the 9-month value, it was found that these values were stable. The experimental environment and data collected in the paper are shown in the Fig. 7.

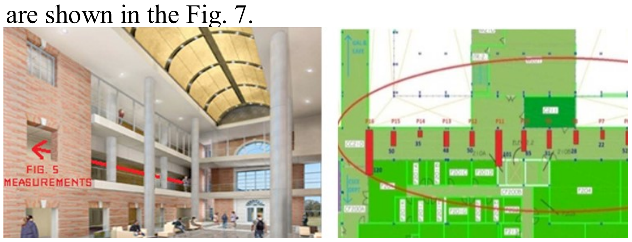

Figure 7. (a) Experimental environment; (b) the magnetic field strength value of column.

At the same time, the dynamic method is used to collect the magnetic field strength of the column, and the data are consistent with the static data.

In view of the above schemes, this paper uses the following method to verify:

When we examined the corridor of the subject building, we found that the magnetic field near the power equipment is very high, such as access control card reader, fire alarm and so on. Experimental scenarios and equipment are shown in Fig. 8.

Figure 8. (a) The first-floor corridor of the subject building; (b) the access card reader; (c) (d) the fire alarm devices.

Therefore, we marked the location of these devices on a plan view, as shown in Fig. 9.

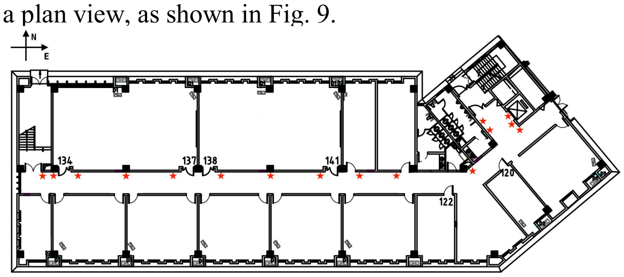

Figure 9. The plan marked with devices.

We will use the following methods to collect the data and verify the method in the paper.

TABLE I. EXPERIMENTAL PURPOSES AND CONTENT

Methods	Experimental contents
Static acquisition. Establish standard data for road signs.	Semi-stationary measurements of each landmark position were made at intervals of 10 cm, 20 cm, 30 cm, 40 cm, 60 cm, 80 cm and 100 cm. The purpose is to test the magnetic field strength of the equipment.
Dynamic verification . Verify the feasibility.	Keeping the distance between the phone and the electrical equipment, through these locations with the normal speed and recording the changes in magnetic field strength. These data will be used for comparison with static acquisition data.

When the distance between the smartphone and the device is 10cm, the Fig. 10 shows that the static data collected at the 16 road signs.

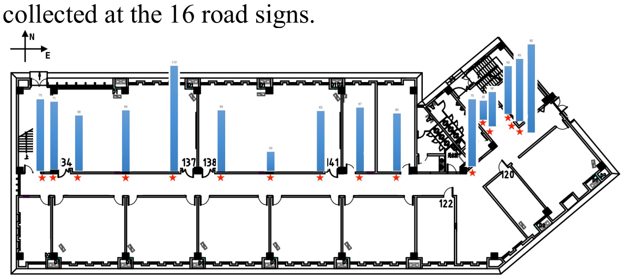

Figure 10. Static acquisition data of 10cm

We analyzed the static data and found that the magnetic field strength value tends to be stable and the discrimination is not high when the distance is greater than 30 cm. As shown in Fig. 11, we compared 5 points where the numerical changes are more obvious.

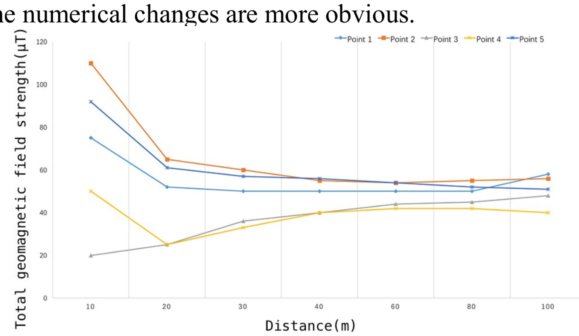

Figure 11. The relationship of static acquisition of magnetic field strength and distance.

We found that the strength of the magnetic field near the electrical equipment has a great relationship with the distance. But it also requires a dynamic test to prove whether it can be used as a basis for positioning. The Fig. 12 shows that the magnetic field of dynamic test with 10cm.

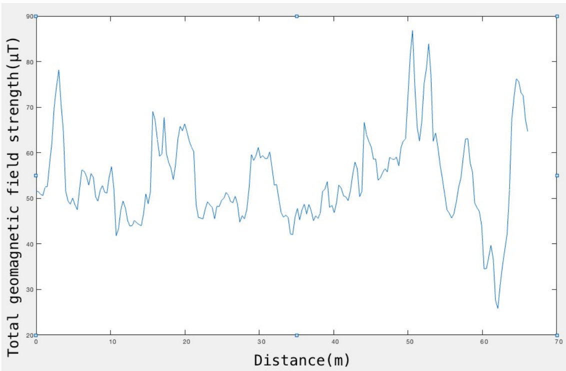

Figure 12. Results of dynamic test with 10cm.

We are trying to fit static and dynamic data when processing data. However, due to the numerical differences between the noise of the handset sensor and the high intensity magnetic field, we have chosen the normal range of path (100cm) data to be fitted, as shown in Fig. 13.

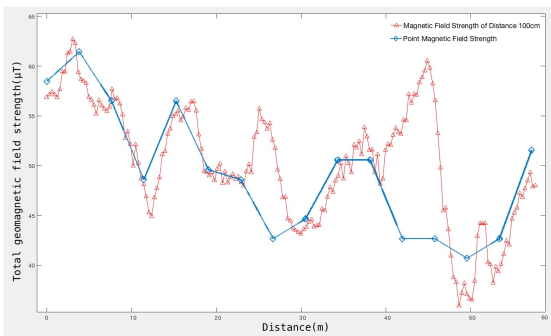

Figure 13. Results of static and dynamic data with 100cm.

It is found that there is a big difference between the dynamically measured data and the static measured data. Therefore, the following problems are made by using the abnormal magnetic strength value of the road signs to build the geomagnetic fingerprint map.

- The magnetic field of the electrical equipment has a small influence range. The distance of this experiment is about 30 centimeters.
- This experiment shows that the two sets of data in the same distance, the two sets of data matching are not high. That is to say that positioning accuracy is not enough.
- In the actual scene, the distance between the positioning device and the landmark position can not be fixed. And in this experiment, the attitude of the smartphone has a greater impact on the magnetic field strength.

Therefore, it is not preferable to use the abnormal magnetic field strength of the electric equipment to construct the geomagnetic fingerprint map.

2) Use the path to combine the magnetic field strength changes to construct the fingerprint map

In addition to using the fixed position of the magnetic field strength as the identification of location, there is another popular scheme. Because the total intensity of the magnetic field is particularly stable, and in the shorter path changes significantly. Chi, Zhang [12] et al proposed a scheme for constructing a geomagnetic fingerprint map, which is implemented by comparing the actual path and the corresponding total magnetic field intensity. The law shows that the law of intensity change is the same, by comparing different models of mobile phones to record the same path of the data. It also solves the problem of the different values of phone measurements in the same location.

At the same time, the paper puts forward a method to construct the geomagnetic fingerprint map of the building by using the idea of crowdsourcing. As shown in Fig. 14, the geomagnetic fingerprint map of the same building is constructed by using the magnetic field intensity collected by different users, which greatly reduces the workload of constructing geomagnetic fingerprint map.

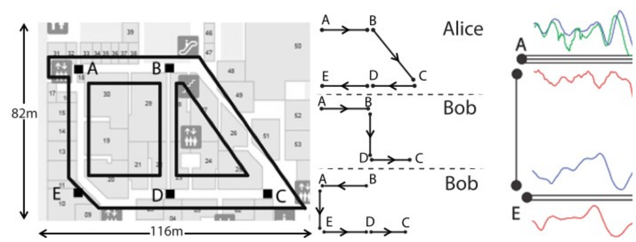

Figure 14. (a) The path of design; (b) a schematic diagram of the virtual fingerprint map building.

Firstly, we collected the total intensity of the indoor geomagnetism with the Nexus 5 with Kesei AK8963 electronic compass. And used these data to simulate the indoor geomagnetic intensity diagram. As shown in Fig. 15.

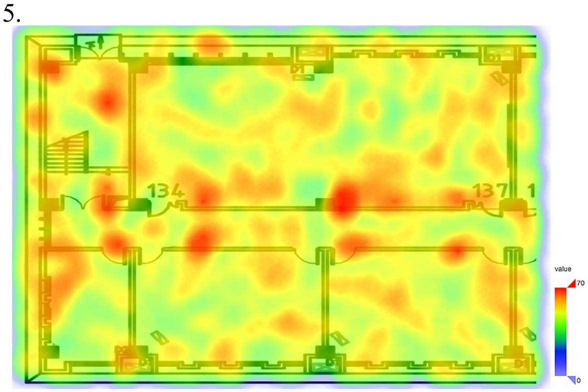

Figure 15. Indoor geomagnetism.

From the above results, we can understand that the indoor environment of the magnetic field does change. So, for the different mobile phone sensors have the same changes in the law? Are these changes unique and can be used in targeting indicators? In response to the above questions, we use the following experiments to verify.

a) The test of differences with smartphone sensors.

We use Nexus5 and honor 4x to test the same path, the path shown in Fig. 16. When we test, the tester uses both mobile phones and keeps the phone more than 30 centimeters apart. In order to simulate the normal walking attitude, the testers use different speeds to walk and put the phone in the pocket during the test.

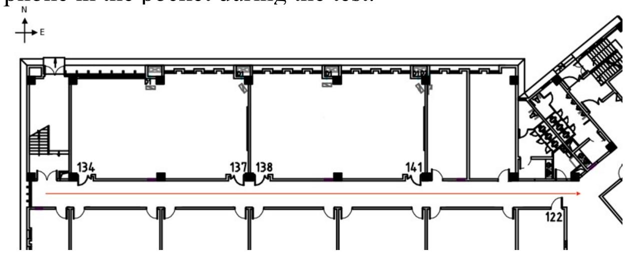

Figure 16. The path to test different smartphone sensor

We processed the data collected by the two phones and get the Fig. 17. From the change characteristics of these original data, the change of the total intensity of the magnetic field on the same path is regular and obvious.

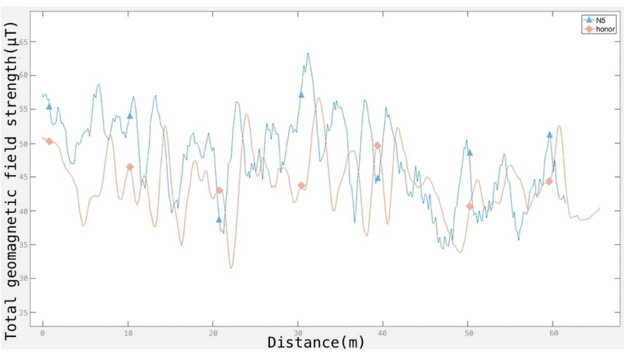

Figure 17. Results of collected data with same path.

b) Variation of the field strength of different paths.

In order to verify that the total intensity variation of the magnetic field can be used as a basis for positioning, we will perform multi-path testing of the indoor environment, including repetitive paths. We plan three test paths in the indoor environment as shown in Fig. 18, where AB segment is the same path, BC, BD, BE are different paths.

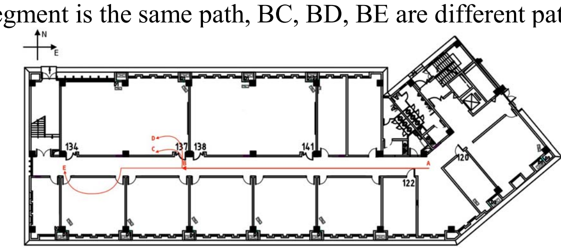

Figure 18. Test path

The above path was tested by using the Nexus 5, and the results are shown in Fig. 19. Through the comparative analysis of the data we found that the same path AB, the sensor three times the data collected basically match. In different paths BC, BD and BE segments, the magnetic field strength data collected by the sensor are completely different.

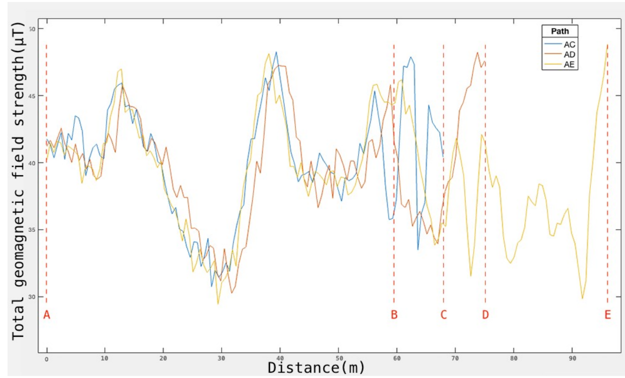

Figure 19. Data analysis results for different paths

Through the above tests, we believe the scheme is feasible which use path and the total strength of the magnetic field to build geomagnetic fingerprint map.

C. Summary

By experimenting with two methods of constructing geomagnetic fingerprint maps, we found that indoor positioning is feasible by using the Earth's magnetic field. The actual performance of the two schemes in constructing the geomagnetic fingerprint map is shown in table 2:

TABLE II. THE ADVANTAGES AND DISADVANTAGES OF BUILDING A FINGERPRINT MAP METHOD

	advantages	**Disadvantages**
Constructing a fingerprint map by using the path combined with the total intensity change of the magnetic field.	1. Solve the difference in the reading of smart phone sensor. 2. The accuracy of the program positioning is higher. 3. The use of crowdsourcing to build geomagnetic fingerprints is highly efficient	Positioning efficiency issues to be resolved. How much distance to move within the indoor range can identify the law of the total intensity of the magnetic field.
Constructing a fingerprint map using the magnetic field strength of a particular location.	1. Special position magnetic field strength stability. 2. The magnetic field strength value of the special position is different.	1. Abnormal magnetic field strength of the impact of small distance, it is difficult to use as a normal positioning basis. 2. As the indoor environment is complex, it can not be universally suitable for all indoor scenes.

IV. CONCLUSION

This paper researches on how to realize the localization problem in the indoor environment, and verifies the feasibility of using the geomagnetic field information for indoor positioning. After researching the geomagnetic field of the indoor environment, the information types of the geomagnetic field are introduced in detail. And how to use this information to build geomagnetic fingerprint maps for indoor positioning in the current sensor accuracy. In the experimental part, we have validated two schemes for constructing geomagnetic fingerprint maps. It is found that it is feasible to use the path combined with the change of the total intensity of the geomagnetic field. For the future of the magnetic field as a room positioning signal source to achieve the feasibility of a step to upgrade. Of course, we will also learn how to efficiently use a shorter path to match the geomagnetic fingerprint map, thereby improving the efficiency of indoor geomagnetic positioning. Due to the errors caused by the sensor equipment, we have not fully utilized the magnetic field information, but we believe that with the development of the science and technology, we can make full use of the indoor magnetic field information for indoor positioning.

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