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Camera-aided Region-based Magnetic Field Indoor Positioning

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***Abstract* - It has been shown that local magnetic field (MF) anomalies can be used in accurate global self-localisation with fingerprinting. However, MF anomalies can only affect limited areas, and the low discernibility of received local MF signals may result in many positions having the same MF-Location information in areas far away from disturbances. This is mainly due to the sensitivity limitations of sensors embedded in mobile phones. This makes it challenging to distinguish between different positions with the same MF value. To address this problem, this paper proposes a new camera-assisted region-based MF fingerprinting technique, which takes maximum advantage of MF-based indoor positioning. Unlike using MF positioning alone for the whole training space, the basic idea of this multipronged system is to use camera-based positioning in areas with fewer disturbances to assist MF positioning targeting attaining a more location estimates. We have calculated the accuracy rate of the proposed system and compared it with MF-only and camera-only localisation systems. The results suggest that the proposed system performs significantly better than these two systems.**

Keywords—magnetic field anomalies; region partition; 3D point clouds model; multipronged system

I. INTRODUCTION

With the high demand for location-based services (LBS), the development of seamless indoor-outdoor positioning systems is expected to become an important trend. To date, outdoor positioning has generally achieved an accuracy and reliability high enough to enable users to navigate using global positioning system (GPS)-based localisation and navigation techniques [1]. However, GPS does not work properly in indoor environments because the transmission signal between GPS receivers and satellites is attenuated and significantly degraded in a multipath environment [2].

The use of several systems and technologies have been proposed to construct and enhance the efficiency of indoor positioning systems, such as GSM [2], Wi-Fi and Bluetooth technologies [3]. Fingerprint-based positioning system can determine the likelihood of targeting an indoor location directly using the information received from users to match with a pre-recorded database of known resource-location information [4]. In the past few decades, fingerprinting techniques based on RSSI of RF signals have been designed by various researchers, such as Wi-Fi [5] and FM [6]. Recently, MF-based location fingerprinting techniques which take advantage of MF anomalies have emerged for use in indoor navigation system. For instance, Ramakanth Putta et al. [7] proposed a method that uses local magnetic field maps in a particle filter based implementation to improve accuracy of indoor localisation.

Theoretically, the Earth's magnetic field (EMF) is an omnipresent and location-specific signal [8]. There are several ways to exploit the MF for localisation purposes. This paper's method involves leveraging this intrinsic resource of the Earth as fingerprints. Since the local MFs in steel-frame buildings could be influenced by both natural and man-made sources(e.g., steel and reinforced concrete structures, electric current, and electronic appliances) [9], which may cause anomalies in the local MF inside the building, it is a promising resource that can be used in accurate global self-localisation with fingerprinting [10]. Compared with other existing indoor localisation strategies, the MF system is cheaper and more energy-efficient while possessing the same precision, and it uses built-in EMF sensors on smartphones without any extra infrastructure [11].

However, MF anomalies can only affect limited areas [12]. Due to the sensitivity limitations of the sensors embedded in mobile phones, the low discernibility of received local MF signals may caused many positions have the same MF-Location information in areas far away from disturbances, [8]. This makes it challenging to distinguish between different positions of the same local MF value [13]. To address this problem, a visual-based indoor positioning technique is introduced here to aid and improve the original MF localisation system with a monocular camera. As with other fingerprint-based positioning systems, this technique uses feature points of images as the matching resource. The location where an image was captured by a user can then be detected by comparing query image with the pre-built image database. Unlike other methods, this technique can also show the location of the user on a visual 3D map of the indoor environment, which can help users to recognise their position more intuitively [14].

This paper proposes a new camera-assisted region-based MF fingerprinting technique for indoor positioning. Instead of using MF positioning alone for the whole space, the basic idea of this method is to use camera-based positioning to assist MF position targeting to estimate the users' location more accurately. After we partition the target area based on the distribution of disturbances, camera-based indoor positioning is used to detect the location of the area with weak discernibility of the MF signal. This region-based method not only increases the accuracy of positioning and reduces the mismatching rate, but also eliminates the possibility of some positions having the same information because a unique image is acquired at these positions. Our results show that camera-assisted region-based MF fingerprinting for indoor positioning provides more reliable solutions than either image and MF matching in areas that have large mismatch rates or indistinctive magnetic features.

The remainder of the paper is organized as follows: Section II introduces some properties of local MF, along with an explanation of the basic theory of proposed system. The main methodologies and the localisation procedure are described in Section III. The experimental set-up and results are analysed in section IV and V respectively. Finally, Section VI summarizes the paper and discusses future work.

II. THEORY

This section discusses a number of properties of the indoor local MF. Some are favourable for indoor localisation purposes, whereas others bring challenges that need to be overcome.

The planet Earth is often visualised as a huge dipole magnet [15]. The EMF signal is omnipresent and stable, as its signal can be sufficient to propagate through the Earth [8]. Using the EMF for positioning is a cost-effective and energy-efficient method which can be used without any pre-installed infrastructure [11]. More importantly, local MFs inside steel-frame buildings may cause distortions and make anomalies due to the influence of both natural and man-made sources (e.g., steel and reinforced concrete structures, electricity, and electronic appliances). This enables a unique MF fingerprint map to be used in indoor self-localisation [9-10].

In general, there are two types of MF distortions: variations and perturbations. As variations are often caused by natural factors on a large scale, they may take a very long time to process. However, the perturbations are of greater concern. These are produced by local factors, such as electrical currents, electrical devices, or any structures which used ferrous materials in their construction [15]. Local MFs close to these disturbances may vary wildly from those further away. However, since the distortions vary depending on their location, this undesired property might further improve the localisation performance.

Unfortunately, MF anomalies can only affect limited areas [12]. For some area of fewer disturbances, the performance of MF positioning still suffers from accuracy and discernibility degradation due to the sensitivity limitations of embedded-sensors in mobile phones. This may lead to many consecutive positions in areas far away from disturbances will receive the same local MF signal values, which may make it rather difficult to distinguish between these positions when conducting the magnetic matching [8].

Fig.1 clearly demonstrates this problem. Compared with drastic fluctuations of MF values close to disturbances (computers), the values in the areas away from such perturbations do not have major differences. Accordingly, this paper uses a monocular camera to conduct the positioning in these weak areas.

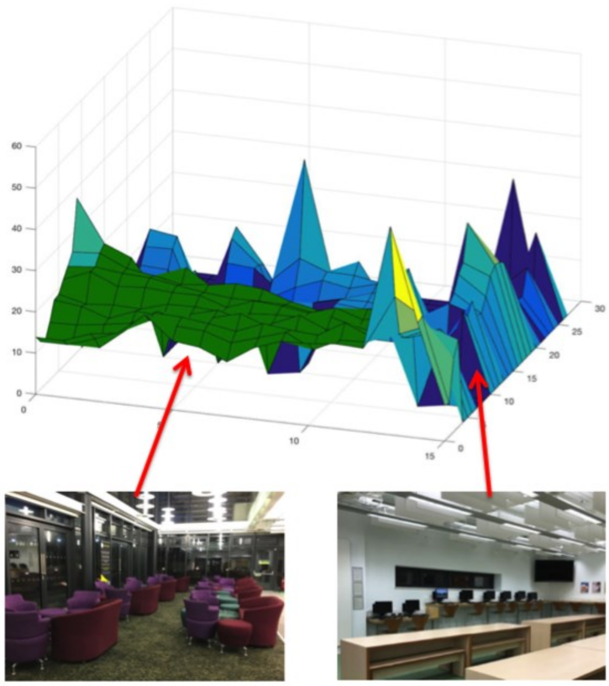

Fig. 1. Example of MF anomalies caused by perturbations

III. METHODS

Generally, the main idea behind the fingerprinting technique when positioning indoors is to obtain the user's location by matching received information from user with data in a pre-recorded database of known resource-location information [4]. This method can be briefly processed into two separate stages: an offline stage for pre-training a resource-location database, and an online stage for determining the target position using an optimal matching algorithm.

The MF and image can be considered as the matching resources. Fingerprinting techniques based on these two resources use a similar idea consisting of the above two stages. This section will introduce both these techniques separately, as well as our proposed method.

A. Magnetic Field Indoor Positioning

A MF fingerprint usually consists of four components: three EMF vector projections in the X, Y, and Z axes and a corresponding magnitude calculated by the first three elements [16]. Naturally, as with other fingerprinting techniques, MF-based fingerprinting contains two main phases.

- Offline training phase: To generate an MF-location database for further matching and positioning, MF values are collected and stored as reference points with their corresponding location information using a mobile phone in every selected point for a certain period.
- Online positioning phase: An optimal matching algorithm is used to obtain the target location by comparing the online information generated by observation with reference points from the pre-built

dataset. The reading in the database most similar to the target signal will be assigned as the estimated location.

B. Single Camera Indoor Positioning

In our previous work, we designed a new optical sensing-based indoor positioning technique by improving the Perspective-n-Point (PnP) problem. In this system, feature points of indoor images are viewed as the parameter for both fingerprinting and the further matching algorithm.

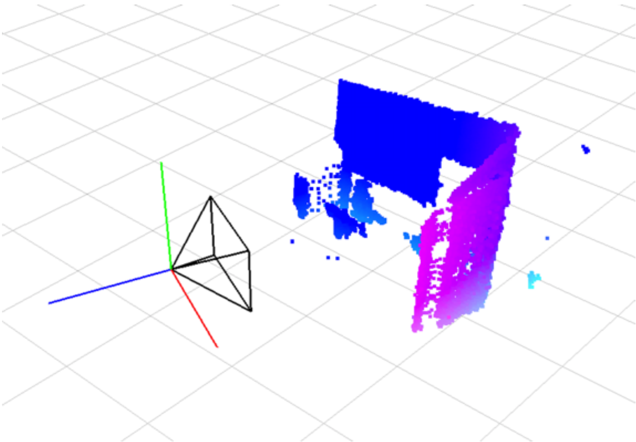

Fig. 2. Example of 3-dimensional model scanning

- Before generating a feature database, a pre-scanned 3-dimensional (3D) model of the indoor environment should be constructed offline with a monocular camera, as shown in Fig.2 (We use a new device named Project Tango from Google.). Once the model is generated, all the 3D point clouds are joined to form an integrated feature database along with their intensity information and a list of the 3D to two-dimensional (2D) projection correspondences of each feature point. To make it easy to find the best-matching image, an index of distinguishing features is generated from all the saved images as well.
- In the online stage, the core of our system uses the brute-force matching algorithm to accomplish a similarity comparison between a query image and the 3D model. In this case, the best match is determined by both the quantity and quality of the matched sets in every reference image. Once the 2D best-matched image is found, the information on the 2D projections will return to the correspondence list. The PnP problem will then be used to retrieve the estimated pose.

C. Proposed Method

As mentioned above, each position inside the steel-frame buildings should theoretically possess a unique local MF value, and anomalies caused by local disturbances may cause nearby MF signals to vary wildly. However, this undesired phenomenon makes the location-based MF signals more unique so that the positioning accuracy can be improved. All this sounds good in theory, but may not work well in practice. Unfortunately, for positions nowhere near local disturbances, the restrictions of the mobile phone's built-in sensors may cause users receive the same signal value in many consecutive positions. This result would confuse the positioning.

As a result, it is unlikely that MF-fingerprint based indoor positioning would be optimal for the whole training space spanned by the sample set [17]. In order to improve the accuracy of the positioning system, different regions of the feature points would require different fingerprinting techniques due to the differing distributions of disturbances. Our method partitions the target space into several cells, then uses a monocular camera to assist with the positioning in areas with fewer disturbances in order to improve the overall precision of the results.

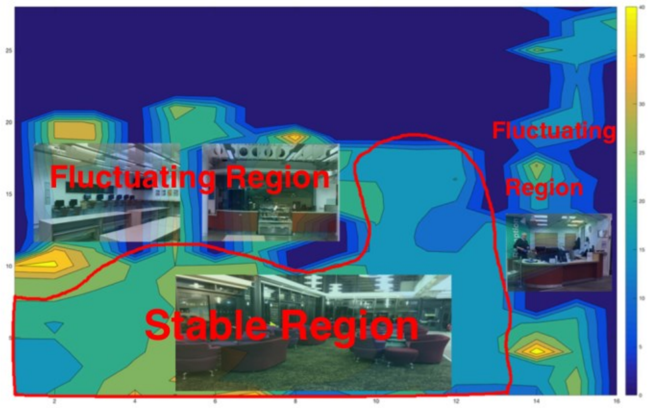

Fig. 3. Example of region partition

Fig. 3 is an example of how we partitioned the targeting area. Considering the characteristics of the local MF signal in the indoor environment and based on the degree of variance between the MF values, we are planning to divide the testing area into two sub-regions: the stable and fluctuating regions. An MF map can clearly indicate that a region with a lot of perturbing aspects(i.e., computers, reinforced concrete walls, and electronic devices) may experience an evident fluctuation of such MF values that we named it Fluctuating-Region. In this case, MF fingerprinting could perform well in positioning. Inversely, an image fingerprint is ideal for Stable-Region with few disturbances.

The proposed localisation method consists of two main phases: the calibration phase, and the positioning phase.

The *calibration phase* is accomplished in two steps. These are:

1) Fingerprint database: generate both the MF map and the 3D visual map offline.

2) Region partition: divide the targeting area based on the MF map.

The *positioning phase* is accomplished online, and consists of two parts:

1) Stable Region: Using the single camera to capture a picture in the current pose, conduct a comparison with the feature point database to retrieve the coordinate information of the query image.

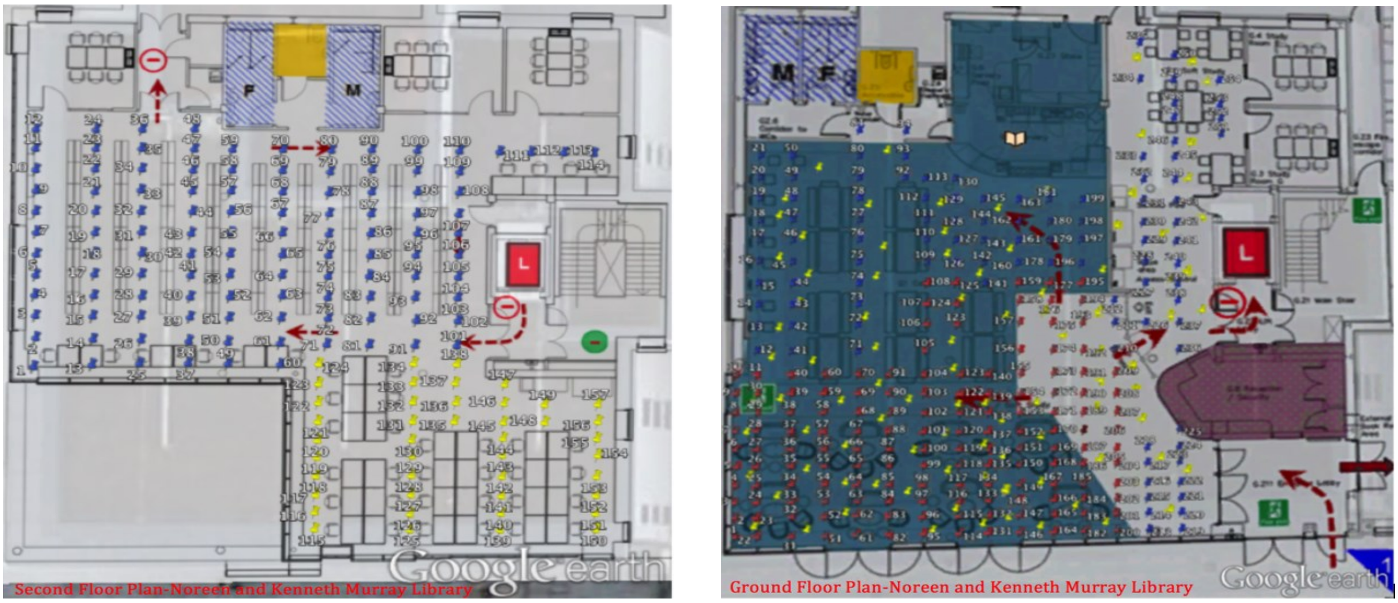

Fig. 5. Floor plans of two test areas with MF sample points

2) Fluctuating Region: Set the MF-location database as the reference database to obtain the estimated location.

The whole process is shown in Fig. 4.

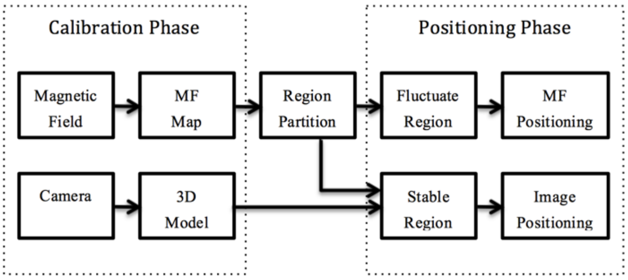

Fig. 4. Whole process of the proposed localisation method

IV. Experimental Set Up

Two sets of experiments were conducted to evaluate the performance of our proposed method. The second floor (with abundant disturbances) and the ground floor (with fewer disturbances) of the Noreen and Kenneth Murray Library building (part of the King's Buildings within the University of Edinburgh) were set as the experiment site, as shown in Fig. 5 and Fig.6. The operation areas were 279 m^2 and 335 m^2.

Fig. 6. Environment of test areas

In order to use a newly-released piece of technology, we used a new tablet from Google named Project Tango to generate a 3D viewing map of the indoor environment. Additionally, it was easier to acquire the location information with the help of its specific depth sensor. However, due to frame constraints and orientation problems with this new device, the built-in accelerometer did not work properly. Instead, we used a smartphone Google Nexus 5X to do both the calibration and positioning for the MF-based indoor positioning.

To validate the system's performance, two comparison tests were conducted using the same devices. One used MF matching only for the whole area, while the other used the monocular camera only. As discussed above, both comparison tests and our region-based system need to use these two techniques to calibrate the entire test environment separately. However, in order to reduce the risk of error caused by the orientation of the mobile phone, all the calibrations in these experiments were in only the one-dimensional case.

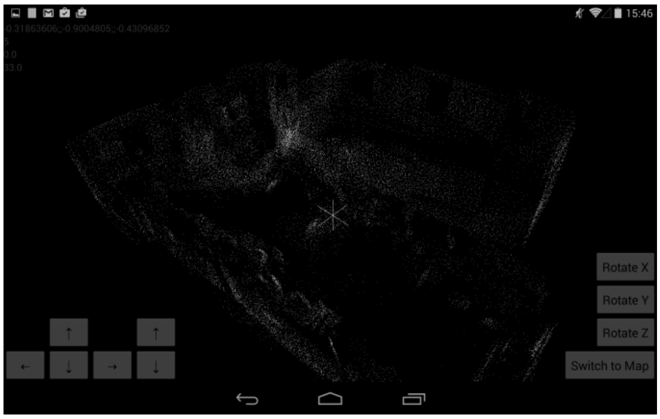

Fig. 7. Example of the 3D model

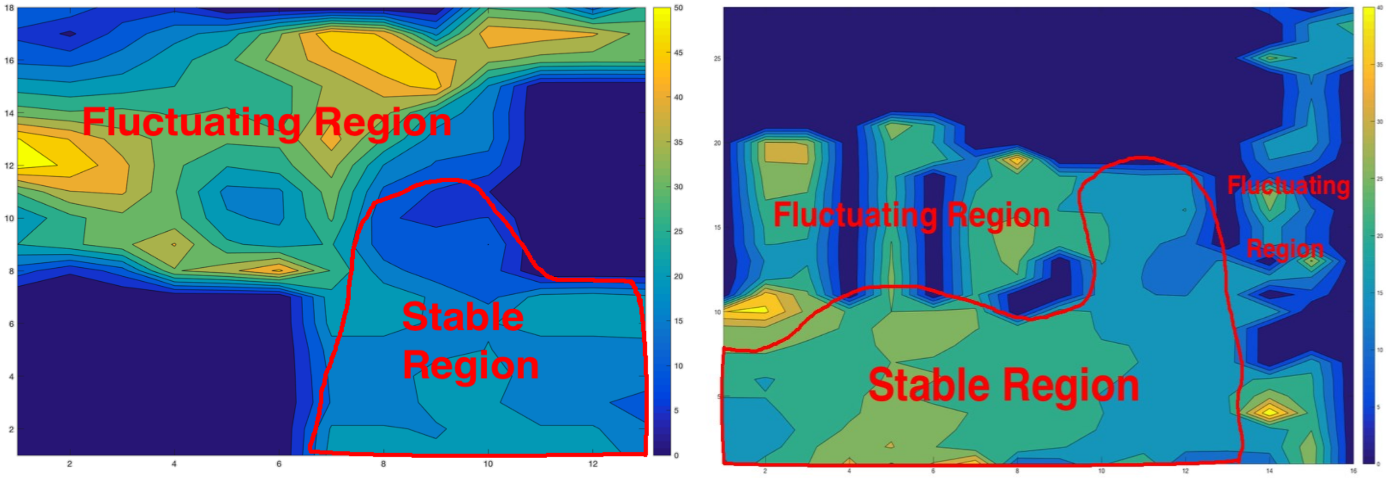

Fig.8. Final partition results (Left: Second Floor; Right: Ground Floor)

To establish the MF fingerprinting map, the surveyor used a developed application to record the MF readings at every pre-set position. The training database on the second floor ranged from the zero position and ended at the 157st position with spacing of 1 m and 251 positions were recorded on the ground floor. Both sample points were marked by yellow pins on their floor plans as shown in Fig.5. Additionally, 20 MF measurements were collected at each reference point, so there were 157*20 = 3140 and 251*20 = 5020 sample points in total in each floor. For the camera calibration, Fig.7 shows an example of the 3D model as well as the point clouds for the second floor using a monocular camera.

The next step was to partition the experiment areas. As mentioned in Section 2, the local MF signals close to the disturbances (i.e., computers, reinforced concrete walls, and electronic devices) may vary wildly and be very different from areas further away from such perturbations. Based on the MF maps for each floor, Fig.8 shows all the final partition results. For example, as we can see the in the Ground floor (Right figure), the café and computer areas were stitched together and assigned to a Fluctuating Region as the MF values here changed very quickly. The front area with only a cloth sofa and glass wall was named a Stable Region because the MF values here showed an approximately stable trend. The real scenarios are shown on Fig.3.

TABLE I. NUMBER OF TEST POINTS FOR EACH FLOOR

		Second Floor	**Ground Floor**
Magnetic Field		15	17
Camera		15	17
Proposed System	Fluctuating Region (MF)	9	8
	Stable Region (C)	6	9

To verify the performance of all three systems, 15 and 17 arbitrary test points were selected according to the size of each experiment area in order to obtain the estimated position of user on the second and ground floors respectively. For the proposed method, matching localisation was attempted after the region partition, using both real-time MF readings and images acquired at selected user positions. Table I indicates the number of test points for the three systems on each floor.

V. RESULTS

This section will discuss the results of indoor navigation systems with MF-only, camera-only, and camera-aided MF. Since our proposed multipronged system is based on modifying the original MF-based localisation system, their performance is mainly analysed and evaluated by comparing these two systems.

The first set of experiments was conducted on the second floor with abundant disturbances. In this paper, the K nearest neighbour algorithm was used to estimate the locations of users by finding the best-match sample points from the MF fingerprint database. It is clear from our previous work that instead of using the same K value for the whole training space, dividing the training space by the different similarity to MF degrees of prototypes and giving different values of k to each sub-region could improve the overall matching rate.

Table II shows the performance of K selection with only the MF-based fingerprinting localisation system. Considering the properties of local MF mentioned in Section 2, together with the partition results to this test area, the table shows that the localisation precision was lower in the Stable Region in terms of matching rate (MR) and error distance (ED) than in the Fluctuating Region when supported by the same K value (K=3). The results decreased the overall precision to a very great degree. It is thus preferable to use another technology to aid and improve the MF-based localisation system. Table III compares the localisation performance for MF-only, camera-only and camera-aided MF in terms of matching rate, average mean error and maximum error.

TABLE II. PERFORMANCE OF K SELECTION FOR ONLY MF-BASED INDOOR LOCALISATION

	Stable Region		**Fluctuating Region**		**Whole Space**	
	MR(%)	ED(m)	MR(%)	ED(m)	MR(%)	ED(m)
K=1	58.13	4.9	90.13	1.3		
K=2	54.23	5.4	92.27	1.1		
K=3	56.13	5.1	90.89	1.3	70.24	3.1
K=4	57.03	5.0	90.22	1.3		
K=5	57.89	5.0	89.98	1.3		
K=6	59.21	4.8	89.23	1.4		
K=7	60.32	4.7	89.11	1.4		
K=8	60.01	4.7	88.64	1.5		

TABLE III. THE LOCALISATION PERFORMANCE OF THREE SYSTEMS

		Matching Rate(%)	**Average Mean Error(m)**	**Maximum Error(m)**
Magnetic Field		56.13	3.1	13.1
Camera		77.78	2.1	8.7
MF + C	Fluctuating Region (MF)	92.27	1.1	2.6
	Stable Region (C)	83.33	2.2	6.1
	Overall Space	88.67	1.6	6.1

It is clear from the table that the multipronged system achieved the best overall performance in terms of matching rate and average error distance. When compared with the original MF-based indoor positioning, the max error distance of the proposed system falls from more than 13m to less than 7m. The matching rate of the sample points also improved from approximately 56% to more than 88%.

In localisation mechanisms, average error distance is a key parameter to measure the results. The MF-only system average error distance was almost 3m. After using the camera-based indoor positioning technique in the areas with fewer perturbations, the average mean error is reduced by nearly 50% to 1.6m. We also conducted the same experiment using the camera-only modulus, but the results are no better.

Fig. 9 clearly shows the resulting test points of the three methods. The numbered yellow landmarks represent the locations of the ground truth test points, and the red, blue and green landmarks represent the estimated locations where the MF-only, camera-only and camera-aided MF systems were used respectively. It is clearly shows that the results of the camera-aided MF systems are closest to the actual test points. The following tests were conducted on the ground floor, and show the performance of the region-based camera-aided MF system when there are fewer disturbances.

Fig. 9. Visual result of three methods for second floor

In order to reveal the universal applicability of the proposed system, tests with a variety of levels of interference should be considered. The second set of experiments was conducted on the ground floor of the Noreen and Kenneth Murray Library building. This test used a similar procedure to the first test, but with a different layout. This time an indoor environment with fewer MF perturbations was provided. The static result is shown in the Table IV respectively. In general, it is clear that the proposed system gives the most accurate positioning results.

TABLE IV. THE LOCALISATION PERFORMANCE OF THREE SYSTEMS ON GROUND FLOOR

		Matching Rate(%)	**Average Mean Error(m)**	**Maximum Error(m)**
Magnetic Field	Fluctuating Region (MF)	58.67	4.3	
	Stable Region (C)	89.23	1.1	
	Overall Space	63.52	3.8	15.87
Camera		80.26	2.0	7.6
MF + C	Fluctuating Region (MF)	89.53	1.0	2.1
	Stable Region (C)	82.26	1.9	7.3
	Overall Space	84.32	1.5	7.3

VI. CONCLUSION AND FUTURE WORK

This paper has presented a camera-aided region-based magnetic field indoor positioning system that takes the maximum advantage of local MF anomalies. However, since MF anomalies can only affect limited areas and the sensitivity of the embedded-sensors in most mobile devices is limited, many MF signals received from areas away from disturbances may possibly have the same signal-location information that leads to confusion in identifying their location. Unlike most original MF-based indoor positioning systems that use MF fingerprinting alone to locate users, this multipronged system improves significantly through the utilization of a camera-based visual positioning method in areas with fewer disturbances. By compare the multipronged system together with two competing systems, which were tested with smart mobile devices in different indoor environments, all results show that the camera-aided MF indoor positioning system outperforms others in both accuracy and reliability.

Compared with results using MF alone, the camera-aided MF solution achieves more than a 50% improvement in average error distance in both cases of fewer and abundant disturbance environments. Future work will focus on making an automatic selection for different location technologies for every sub-region in order to provide continuous and self-adaptive solutions.

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