Journal of the Korean Society for Geospatial Information Science
Vol.24 No.2 June 2016 pp.107-112
ISSN: 1598-2955 (Print)
ISSN: 2287-6693(Online)
http://dx.doi.org/10.7319/kogsis.2016.24.2.107

Research Paper

The Study of Particle Filter Localization Algorithm Based on Magnetic Field Data

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Abstract

Most of the indoor positioning algorithms based on magnetic data mainly focus on reducing the accumulated error of the odometry data, such as signals produced by the inertial sensors. However, in most cases such as positioning by using smartphones in the indoor environment, those approaches seem unfeasible due to the absence of the inertial sensors. Thus, in this paper, we try to study a positioning algorithm exclusively based on the magnetic data. We refer to some thinking from the steps of Particle Filter and conduct an experiment to verify the application of the new algorithm. Besides, we use the variance of the result of the previous step to decrease the area to be matched in the next step, intending to improve the accuracy of the results. The result of the experiment shows that the new algorithm has a high probability to match with accuracy less than 2 meters in a 24 meters by 2.6 meters corridor.

Keywords : Magnetic Field Data, Particle Filter, New Algorithm

1. Introduction

As is known to all that human spends more time in indoor environment than in outdoor environment. Compared with the outdoor environment, more daily work and life are completed in indoor environment. Thus, the application of indoor positioning system has a remarkable potential. An indoor positioning system considers the context of the indoor environment. Dempsey defines an indoor environment system as a system that continuously and in real-time can determine the position something or someone in the physical space(Depsey, 2003). Among all the positioning approaches in the indoor environment, the ones based on signal produced by signal transmitters, such as Wi-Fi, Bluetooth or LED, receive most attention in the scientific studies. A typical example is that due to their ability to perform with cost efficient monocular camera sensors, the works by Davison et al. and Klein et al. are important steps towards economic feasibility of mass market applications for indoor localization.

However, due to the high expense of the signal transmitters and the coverage restriction of these signals, in recent years, magnetic data is considered to be the signal source due to its accessibility. As is known to all, the magnetic data exists in all environments on the earth, and using magnetic signals is an old and classic way of position measuring and tracking, such as the direction of birds and some mammals(Fig. 1). The value of magnetic field data considerably changes in the surrounding of the metal materials(Angermann et al., 2012). Therefore, the magnetic field can be used as a positioning field in the indoor environment. In the original studies, the magnetic field data was viewed as an assistance to minimize the accumulated error of the inertial sensors(Table 1).

However, as the application of the smartphones extends, research on the localization algorithm

Received: 2016.06.14, accepted: 2016.07.01

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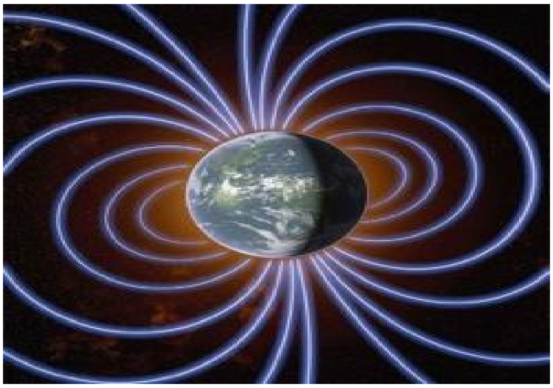


-29.8	-7.73	-38.28	49.12
-28.94	-7.6	-38.38	48.66
-28.75	-7.49	-38.88	48.93
-28.27	-7.38	-38.68	48.48
-27.5	-7.25	-38.78	48.09
-27.2	-7.62	-39.08	48.22
-26.62	-7.6	-39.28	48.06
-26.13	-7.67	-39.48	47.97
-25.58	-7.07	-39.89	47.91

Figure 1. The magnetic lines of the earth and the value of the magnetic data

exclusively based on the data from magnetic sensors of the smartphones receives more attention. Le Grand and Thrun describe the use of magnetic sensors in a smartphone to build a map of the magnetic field, which could enable very economical mass market applications(Grand and Thrun, 2012). The advantages of using magnetic field data are obvious: a. the absence of the coverage restriction of the signal; b. no need for the signal transmitters.

2. The features of magnetic field data

Earth's magnetic field originates from the earth outer core, in which highly conductive liquid iron spins. Compared with those artificial signals used in positioning process, the magnetic field data is a kind of field that do not depend on man-made signal transmitters. The density of the magnetic field data is measured in terms of tesla or gauss. The magnetic field data in earth surface ranges from 25000 to70000 nT.

The magnetic data is a three dimensional vector (x, y, z). In the Fig. 2, the three terms in the front are the value of x, y, z component respectively; the last term is the total value.

Whether a signal can be the source of the localization depends on its stability. Unstable signal cannot be viewed as an effective data source because of the remarkable fluctuation in the localization process. To testify the availability of magnetic field data as an effective data source, in this chapter, we design an experiment to study the stability of the magnetic field data in a fixed point for the length of a day, a week and a month respectively(Fig. 3 and 4). The results are as follows:

As is shown above, the magnetic field is constantly

Table 1. The daily variation of the magnetic field data

Time (h)	X component (μT)	Y component (μT)	Z component (μT)	Total Vaule (μT)
0:00	-4.48	-28.93	-35.02	45.64
0:30	-4.39	-29.03	-35.3	45.91
1:00	-4.48	-29.21	-35.39	46.11
1:30	-4.3	-29.12	-34.83	45.6
2:00	-4.2	-29.12	-35.3	45.95
2:30	-4.3	-29.03	-35.2	45.83
3:00	-4.2	-29.03	-35.02	45.68
3:30	-4.48	-29.03	-35.95	46.42
4:00	-4.11	-29.39	-35.11	45.97
4:30	-4.39	-29.21	-35.2	45.95
5:00	-4.39	-29.3	-35.39	46.16

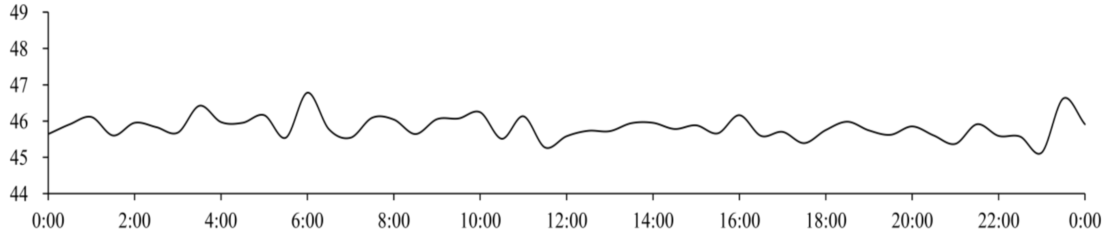


Figure 2. The graph of daily variation of the magnetic field data

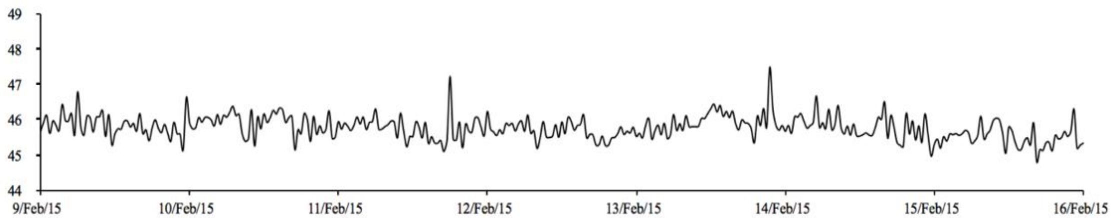


Figure 3. The weekly variation graph of the magnetic field data

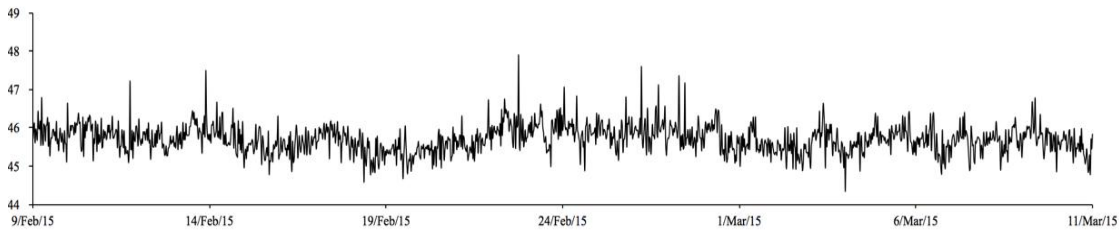


Figure 4. The monthly variation graph of the magnetic field data

stable in the period of a day, a week and a month. In sum, the magnetic field data appear to be stable in the long run. The magnitude of the fluctuations in the outdoor environment ranges from 10 nT to 30 nT, less than 0.5% of the magnitude of magnetic field (LMU Geophysics, 2013). In fact, in the same kinds of terrace, the variations from region to region are minimal. In contrast, the fluctuation in the indoor environment are more drastic, which makes the positioning into feasible.

The metal building materials can cause magnetic torque. In other words, the value of magnetic data surrounding the metal materials in much higher than that of the area far from these kinds of materials. Thus, these differences can be used as features to match.

3. Step Model

Step plays a significant role in the positioning algorithm based on particle filter. In particle filter, the measurement function is updated when the time k transmits to time k+1.

The signal that represents the time transmission is the occurrence of the step. That is, when the user takes another step, the new magnetic data will be add into the measurement function in time, which means the particle filter starts a new circle. Therefore, the judgment for the occurrence of a step is crucial. In this paper, we erect a model to build a connection between the step frequency and step lengthy. In the research, we set up various group of walking and use linear fitting to simulate the relationship between step frequency and step lengthy. The linear fitting equation is 3.013f+69.134.

In addition, the model can be self-taught through adding new data into the linear fitting model. The updated linear fitting equation is L=3.2511f+70.003 (Fig. 5).

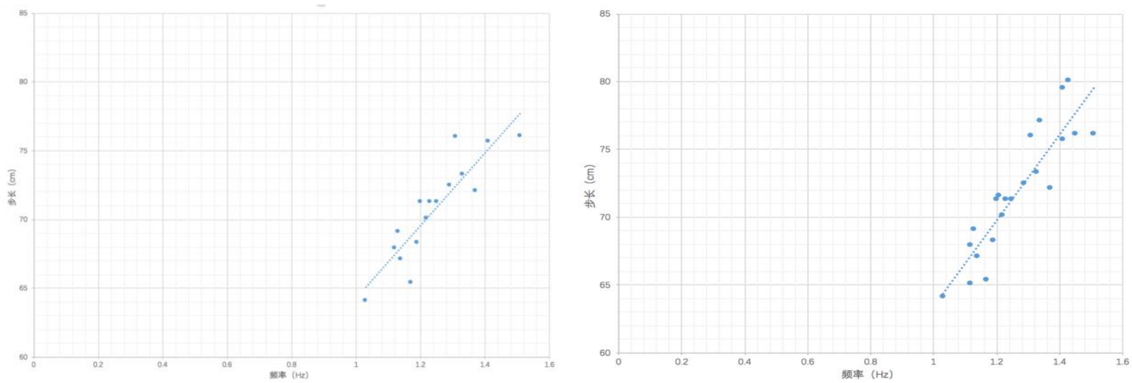


Figure 5. Linear fitting(Left) and updated linear fitting(Right)

4. Localization algorithm based on particle filter and feasibility experiment

4.1 Algorithm

Since the likelihood functions and probability distributions present in this Bayesian filter are strongly multi-modal, we have chosen to use a particle filter (also known as a sequential Monte Carlo filter) with systematic resampling (Sanjeev Arulampalam et al., 2002). We refer to steps from the particle filter algorithm, and generate a likelihood function from the three-variable Gaussian distribution.

First, we collect certain number of groups of data in a second, which means that these groups of data are from the adjacent area.

Second, for every magnetic data given by magnetic sensor, we use traversal algorithm to match all the point in the magnetic-reference map to search the the most suitable point, which receives the highest likelihood in the function, and then record their two coordinates (x, y) in the map. Third, we view the likelihood as weight to calculate an integrated point in this second. As all groups of data are from the adjacent area in a second, we look the integrated point as the position of the sensor in this second.

At last, we calculate the variance of both coordinates of these points to determine the area to be matched in the next steps. Specifically, the magnitude of the discrimination of the likelihood function is in the order of a centimeter(Angermann et al., 2010).

4.2 Experiment Setup

4.2.1 Mapping the magnetic reference map

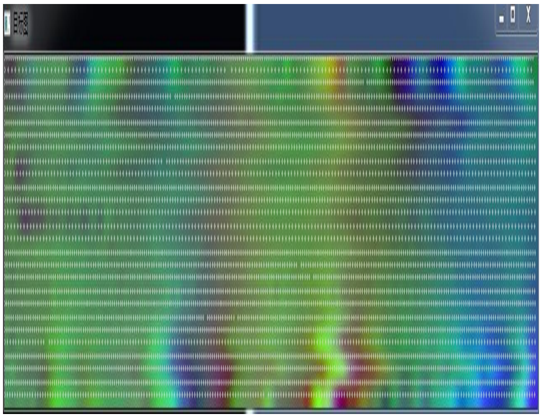
We employ a motion capture system, a locomotive with inertial sensors and magnetic sensors. This motion capture system can collect data at a frequency of 50Hz. In this experiment, we set up the rate at 10Hz. The system yields points with five-dimension data, two coordinates of the points in the reference maps and three components of the point's magnetic data. The experimental area is a 24 meters by 2.6 meters corridor. Through putting the value of three-dimension magnetic data into the corresponding part of RGB respectively, we use OpenCV to draw the reference map.

4.2.2 Positioning simulation

Since we do not know the precise coordinates of the to-be-matched points, we decide to remap the same area with different resolution to simulate positioning process. We use same capture system at different rate, 3Hz, to remap the same area. And then, we choose 10 adjacent points in the second map to localize them in the first map with higher resolution. At last, we compare the position of the point and that of its matched integrated point in the reference map. To simulate the human motion in the indoor environment, we conduct three series of locomotive trace: line, rectangle and circle.

4.3.3 The area to be matched in the next step

Since a person is unlikely to move more than 2 meters in the ordinary walking model, there is no



18.82134	2	-31.43	-8.09	-38.38	50.26
18.92253	2	-31.14	-8.17	-38.18	49.94
19.02372	2	-30.76	-7.96	-38.38	49.82
19.12491	2	-30.85	-7.97	-38.38	49.88
19.2261 2	-29.99	-7.74	-38.48	49.4	
19.32729	2	-29.8	-7.73	-38.28	49.12
19.42848	2	-28.94	-7.6	-38.38	48.66
19.52967	2	-28.75	-7.49	-38.88	48.93
19.63086	2	-28.27	-7.38	-38.68	48.48
19.73205	2	-27.5	-7.25	-38.78	48.09
19.83324	2	-27.2	-7.62	-39.08	48.22
19.93443	2	-26.62	-7.6	-39.28	48.06
20.03562	2	-26.13	-7.67	-39.48	47.97
20.13681	2	-25.58	-7.07	-39.89	47.91
20.238 2	-25.11	-6.67	-40.09	47.77	
20.33919	2	-24.14	-6.82	-40.39	47.55
20.44038	2	-23.65	-6.99	-40.29	47.24

Figure 6. The magnetic reference map(Left) and The 5-dimension data (Right)

Table 2. The correlation between the variance of the result of the previous step and the area to be matched in the next step

Variance of the coordinates of 10 points in the k step	Area to be matched in the k+1 step
Variance < 1	Radius = 3
1 < Variance < 10	Radius = 6
10 < Variance < 20	Radius = 9
Variance > 20	Radius = 12

need to match the all reference map. The area to be matched in the next step can be adjusted to a rather small one to improve the accuracy.

Here we use the variance of the coordinates of the 10 points in the k step as the standard to adjust the area to be matched in the k+1 step(Table 2). In landslide inventory mapping, images with good spatial resolution are most widely.

Conventional Aerial Photography included only photographs in RGB or NIR bands, but now it has been widely replaced by digital photogrammetry and also by high resolution satellite imagery such as GeoEYE, QuickBird, IKONOS, SPOT-5 etc. With introduction of Unmanned Aerial Vehicles (UAV) difficult area with high and ultra-high resolution imageries are now possible.

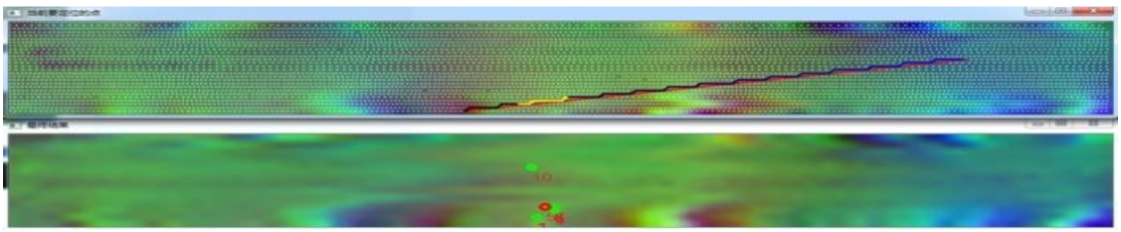


Figure 7. The result of Line positioning simulation

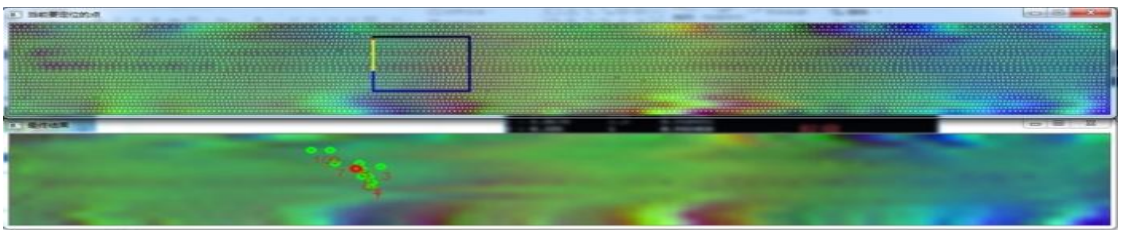


Figure 8. The result of Rectangle positioning simulation

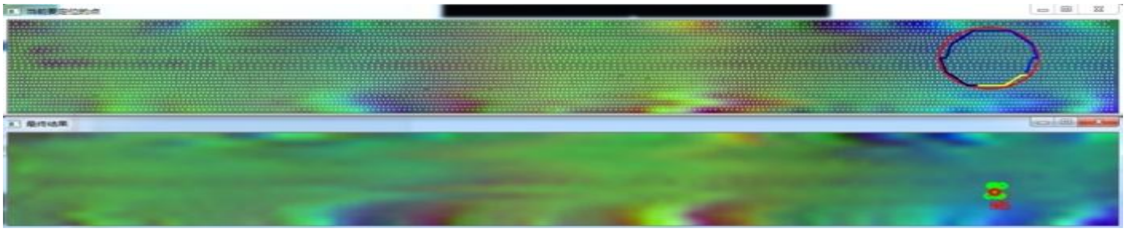


Figure 9. The result of Circle positioning simulation

5. Results and discussion

Fig. 6 is the magnetic reference map with higher resolution, 10Hz. Each white dot in the map represents a point measured the two coordinates of the map and the three components of the magnetic field data by the capture system(the first map is the simulation positioning map, the second map is the reference map). Although the 10th point deviates from the correct position, there are 9 points remaining in the correct adjacent area. Thus the calculated coordinates of the integrated point (red) is close to the reality(Fig. 7). The variance of the 10 points is minimal, and the difference between the real points and the integrated point after localization is small(Fig. 8). The best outcome. The variance of the 10 points is minimal, and the difference between the real points and the integrated point after localization is least(Fig. 9). The results of the experiment show that, in the 24 meters by 2.6 meters corridor, the new algorithm exclusively based on the magnetic field data has a high probability to position successfully at a high accuracy. The different types of the locomotive trace do not remarkably influence the result of the positioning process.

5. Conclusions

In this paper, we draw lessons from the particle filter, and design a new algorithm to exclusively use magnetic data to position. It works in the relatively small size area such as in the corridor. And the thinking that adjusting the area to be matched is based on the results of the previous step indeed improves the accuracy. However, for a bigger area, the accuracy undoubtedly decreases because there are always similar points in wrong part of the map. Finding reasonable standards to remove these wrong point is what should be studied in the next.

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