A Smartphone Short-Range Path Estimation with Hyperbolic Function for Spinning Magnet Marker

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I. Introduction

Recently, an importance of location information has increased with the spread of smartphones. Our purpose is to estimate a smartphone position with an error within several centimeters. In addition, we would like to recognize behavior patterns of people, and targets of their interest. These information will provide new services. One method that can estimate a position of devices by a few centimeters error is using dynamic magnetism. However, it is difficult to apply these positioning methods to a smartphone. This is because a sampling frequency of a smartphone is dozen of hertz, whereas these methods use a dynamic magnetic field with several kilohertz [1], [2]. We have developed a Spinning Magnetic Marker (SMM), and proposed a positioning method based on a dynamic magnetism which can be applied to a smartphone [3], [4]. In this study, we propose a method to estimate a short-range path of a moving smartphone by curve fitting with hyperbolic function.

II. Estimation Method

A. Magnetism Equation

In order to estimate a short-range path of a smartphone, we formulate the magnetism generated by the SMM. We limit the short-range path of a smartphone in a two-dimensional plane and consider only the x-axis and the y-axis component of magnetism for this time. Fig.1 shows relationship between the SMM and magnetism measured by a smartphone at (r, θ). In this figure, t denotes time, and ω denotes an angular velocity of the magnet. H_r denotes radius-component of magnetism measured by a smartphone. H_θ denotes angle-component of magnetism measured by a smartphone. When we approximate magnetism generated by an SMM as magnetism generated by magnetic dipole, H_r and H_θ are written as follows using constants A, B.

$$H_r = \frac{A}{r^3} \tag{1}$$

$$H_\theta = \frac{B}{r^3} \tag{2}$$

Then, we can derive the x-axis and the y-axis component of magnetism measured by a smartphone as follows using (1)(2).

$$H_x = \frac{A}{r^3}\cos(\theta - \omega t)\cos\theta - \frac{B}{r^3}\sin(\theta - \omega t)\sin\theta \tag{3}$$

$$H_y = \frac{A}{r^3}\cos(\theta - \omega t)\sin\theta + \frac{B}{r^3}\sin(\theta - \omega t)\cos\theta \tag{4}$$

Furthermore, we can derive an equation of a magnetic norm H from these equations as follows.

$$H = \sqrt{\frac{B^2}{r^6} + \frac{A^2 - B^2}{r^6}\cos^2(\theta - \omega t)} \tag{5}$$

By substituting functions representing a smartphone short-range path into r, θ in (5), approximate equation of a magnetic norm in that short-range path is derived.

We assume that a smartphone moves at constant speed. In addition, we consider two short-range paths, a straight path and a path that a smartphone turns direction at the closest point from SMM. We describe these two short-range paths using hyperbolic function as follows.

$$x = a\cosh(v(t - t_0)) \tag{6}$$

$$y = b\sinh(v(t - t_0)) \tag{7}$$

We perform curve fitting to a measured magnetic data using (5)(6)(7) with a, b, v and t_0 as fitting parameters. Then, an initial position and velocity of a smartphone is calculated from these fitting parameters.

III. Experiment

A. Experiment Preparation

In order to evaluate a smartphone short-range path estimation method, we made a belt conveyors. Since metallic materials become magnetized, we created frames and pulleys by plastic using a 3D printer. In addition, we used screws made of polycarbonate, and nuts made of vinyl chloride. Fig.2(a) shows the experiment situation using belt conveyors. We set the magnet spinning cycle of the SMM to 1Hz. We used an

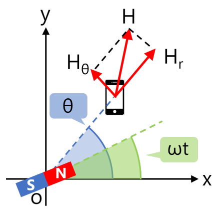
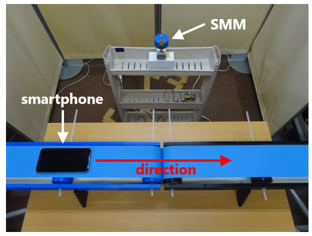
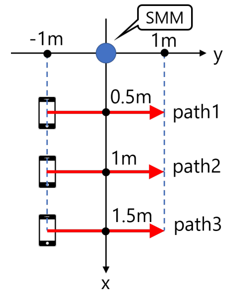


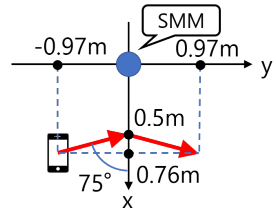
Fig. 1. Magnetism by an SMM



(a) Experimental setup



(b) Path 1, 2, 3



(c) Path 4

Fig. 2. Configuration of experiment

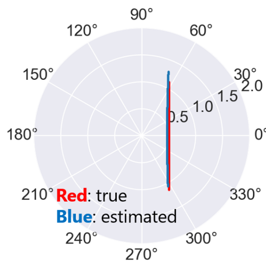


Fig. 3. Comparison between a true path and an estimated path

TABLE I
ESTIMATION RESULTS OF PATH 1, 2, 3

	Path1			Path2			Path3		
	cm		m/s	cm		m/s	cm		m/s
	x_0	y_0	v	x_0	y_0	v	x_0	y_0	v
True	50	-100	0.1	100	-100	0.1	150	-100	0.1
ME	1.6	4.7	<0.01	4.6	9.4	<0.01	12.4	45.0	0.03
SD	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	13.3	22.1	0.01

iPhone 6 Plus with a sampling frequency 100Hz. Fig.2(b)(c) shows three short-range paths of a smartphone estimated in the experiment. We conducted experiments 5 times on each path and evaluate each estimation accuracy.

B. Experiment Result

Table I shows estimation results for path 1, 2, 3. This table also shows that a mean error of an estimated initial position is within 10cm and velocity is within 0.01m/s at the closest distance up to 1m. However, when the closest distance is 1.5m, the estimation accuracy declines precipitously. The is because the magnetic norm decreases in inverse proportion to r^3, as shown by (5), so it can not measure the magnetism for estimation as the distance increases. Fig.3 shows a comparison between a true path and an estimated path about path 1. As shown this figure, the true path and the estimated path almost coincide. Table II shows estimation results for path 4. This result shows that when the closest distance is 0.5m, the estimation accuracy is lower than path 1.

IV. CONCLUSION

In this research, we proposed a smartphone short-range path estimation method using an SMM. First, we derived approximate equations of magnetism detected by a moving smartphone. Next, we proposed a method to estimate the short-range path by curve fitting by approximate equations substituting hyperbolic function. As a result of experiments, we estimated a initial position within a mean error 5cm, and velocity as a mean error 0.01m/s within the distance 1m from the SMM. From these results, when the closest distance from the SMM is within 1m, we achieved three smartphone short-range paths estimation with an accuracy within several centimeters. However, the proposed method can only estimate a limited short-range path of a smartphone. Since an pedestrian moves on a more complicated route, it is necessary to consider a method to estimate more complicated path. In addition, a coverage where the estimation accuracy is within several centimeters is only 1m from the SMM. Since a pedestrian moves at a speed of more than 1m per second, this coverage is insufficient to know the tendency of pedestrians.

TABLE II
ESTIMATION RESULT OF PATH 4

	Path 4		
	cm		m/s
	x_0	y_0	v
True	50	-100	0.1
ME	3.1	22.0	0.03
SD	0.03	<0.01	<0.01

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