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 a few centimeters error. In addition, we would like to recognize behavior patterns of people, and targets of their interest. These information will provide new services. For example, at an event venue, it will be possible to provide information about other exhibits according to their positions. There is a method that can estimate a position of a magnetic sensor with a few centimeters error is using dynamic magnetism. This method is available even if under strong environmental magnetism because it uses frequency of dynamic magnetism to positioning. However, it is difficult to apply these positioning methods to a smartphone, because a sampling frequency of a magnetic sensor mounted on a smartphone is dozen of hertz, whereas these methods use a dynamic magnetism with several kilohertz [1], [2]. Therefore, we developed a Spinning Magnetic Marker (SMM) which generates dynamic magnetism by spinning a strong magnet, and proposed a positioning method based on 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 the hyperbolic function, and curve fitting with magnetism equation.

II. ESTIMATION METHOD

A. Magnetism Equation

In order to estimate a short-range path of a smartphone, we formulate magnetism generated by an SMM. We limit the short-range path of the smartphone in a two-dimensional plane and consider only the x-axis and the y-axis component of magnetism in this paper. 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 a magnet attached on the SMM. H_r denotes radius-component of magnetism. H_θ denotes angle-component of magnetism. When we approximate magnetism generated by the SMM as magnetism generated by a magnetic dipole, H_r and H_θ are written as equations inversely proportional to r^3. Therefore, we can derive the x-axis and the y-axis component of magnetism measured by a smartphone at (r, θ) using constans A, B as follows.

$$H_x = \frac{A}{r^3}\cos(\theta - \omega t)\cos\theta - \frac{B}{r^3}\sin(\theta - \omega t)\sin\theta \quad (1)$$

$$H_y = \frac{A}{r^3}\cos(\theta - \omega t)\sin\theta + \frac{B}{r^3}\sin(\theta - \omega t)\cos\theta \quad (2)$$

Furthermore, we can derive an equation of a magnetic norm H from (1)(2) as follows.

$$H = \sqrt{\frac{B^2}{r^6} + \frac{A^2 - B^2}{r^6}\cos^2(\theta - \omega t)} \quad (3)$$

By substituting functions representing a smartphone short-range path into r, θ in (3), approximate equation of a magnetic norm in that short-range path is derived. In this paper, we use the hyperbolic function to represent the moving smartphone path so that we can estimate not only the straight path but also the bend path. We assume that a smartphone moves at constant speed, and describe the short-range path of the moving smartphone using hyperbolic function as follows.

$$x = a\cosh(v(t - t_0)) \quad (4)$$

$$y = b\sinh(v(t - t_0)) \quad (5)$$

We perform curve fitting to a measured magnetic data using (3)(4)(5) 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 the smartphone short-range path estimation method, we made belt conveyors. Since metallic materials is magnetized, we made 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 experimental set up using belt conveyors. We set

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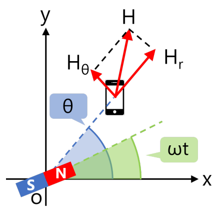
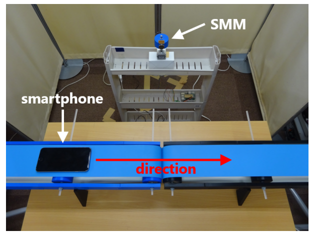
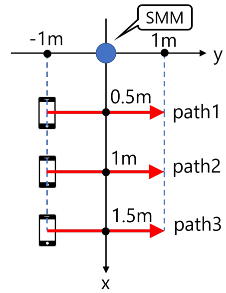


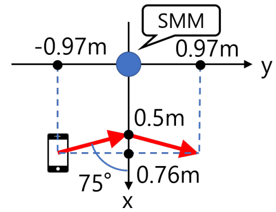
Fig. 1. Magnetism by an SMM



(a)Experimental setup

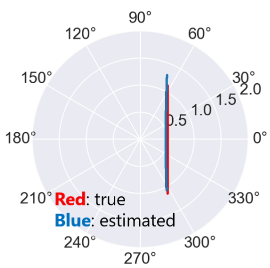


(b)Path 1, 2, 3

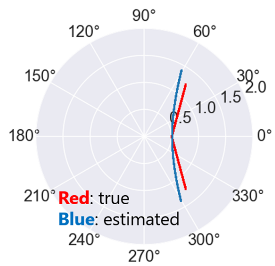


(c)Path 4

Fig. 2. Configuration of experiment



(a)Result of path 1



(b)Result of path 4

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

a magnet spinning cycle of the SMM to 1Hz. We used an iPhone 6 Plus with a sampling frequency 100Hz. Fig.2(b)(c) shows four short-range paths of the smartphone estimated in the experiment. We conducted the 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. This is because the magnetic norm measured by the smartphone decreases in inverse proportion to r^3, as shown by (3). Fig.3(a) shows a comparison between the true path 1 and the estimated path 1. As shown this figure, the true path and the estimated path almost coincide in case of path 1. Table II shows estimation results for path 4. Although the estimation accuracy lower than that of path 1, the mean error at the initial position of x is within 3.1cm. Fig.3(b) shows a comparison between the true path 4 and the estimated path 4. As shown this figure, the estimated path 4 become a hyperbolic curve according to the true path 4.

TABLE I
ESTIMATION RESULTS OF PATH 1, 2, 3

	Path 1			Path 2			Path 3		
	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

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

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 of the moving smartphone by representing the path as the hyperbolic function, and curve fitting with magnetism equation. As a result of experiments, we estimated the initial position of the straight path within a mean error 5cm at the distance 1m from the SMM. Moreover, by representing the moving smartphone path by the hyperbolic function, we estimated not only the straight path but also the bend path. As a future work, it is necessary to consider a method to estimate more complicated path.

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