A Low-Cost Tracking Method Based on Magnetic Marker for Capsule Endoscope

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***Abstract* - In this paper, a position tracking method based on a magnetic marker and hall sensors array, which could be used in capsule endoscope localization, is introduced. The experiment setup is shown, together with the minimization algorithm to analyze the data. It was demonstrated that the calculated position errors could be around 2mm when the marker is moving with a velocity of 2mm/s. Compared with other tracking system, this system cost much lower.**

Index Terms – Tracking; Magnetic marker; Hall sensors; Minimization algorithm.

I. INTRODUCTION

Gastrointestinal (GI) endoscope is widely used in order to find diseases such as stomach and colon cancer, ulcerative colitis, etc, at their early stage. To minimize the suffering of the patient, a capsule endoscope has been developed [1]. The capsule is swallowed by the patient and transmits pictures of an internal GI tract wirelessly. With the aid of peristalsis, it moves passively through GI tract.

As the capsule is not controlled from outside, it's hard to know where it is. At present, doctors only rely on the features and taken time of received pictures to estimate the position. It's not accurate and depends much on the experience of doctors. Knowing the exact position where the pictures are taken will surely optimize diagnose.

Magnetic motion capture is useful to detect hidden objects and provides low cost system compared with image or optical system. It can not only detect the orientation of the magnetic dipole, but also the depth. Moreover, the magnetic field is convenient to use and non-invasive, so it's safer for human body. This kind of methods had once been used for GI mobility studies [2].

In this paper, we insert a cylindrical magnet into a capsule and discussed the application of the magnetic motion capture method to the capsule tracking. This method is based on a combination of the magnetic field measurement and signal-processing technique with the use of magnetic marker and sensors. The results of experiments show the feasibility that this method can be applied to capsule endoscope tracking.

II. MAGNETIC TRACKING METHOD

When the distance from a magnetic field generator is very large compared with its characteristic length, we can make a dipole assumption. Magnetic flux density around a magnetic dipole source is expressed by equation (1):

$$\overrightarrow{B_{cal}} = \frac{\mu_0}{4\pi}\left(-\frac{\vec{m}}{r^3} + \frac{3(\vec{m}\cdot\vec{r})\vec{r}}{r^5}\right) \tag{1}$$

where $\vec{m}$ is the magnetic moment of marker, $\vec{r}$ is position vector of marker. As shown in Fig. 1, everything will be known about the dipole if the six parameters *m, x, y, z, θ* and *Φ* are known.

The strength of the magnetic field at a given position (x, y, and z) can be divided into 3 orthogonal components defined by the unit vector quantities $\hat{i}$, $\hat{j}$ and $\hat{k}$:

$$\begin{aligned}B_{cal}(x,y,z,\theta,\phi) &= B_x(x,y,z,\theta,\phi)\hat{i} + \\ &B_u(x,y,z,\theta,\phi)\hat{j} + B_z(x,y,z,\theta,\phi)\hat{k} \\ &= \frac{\mu_0 m}{4\pi r^5}[(M_x(2x^2-y^2-z^2)+3M_y xy \\ &+3M_z xz)\hat{i} + (M_y(2y^2-x^2-z^2) \\ &+3M_x xy + 3M_z yz)\hat{j} + (M_z(2z^2-y^2-x^2) \\ &+3M_x xz + 3M_y yz)\hat{k}\end{aligned} \tag{2}$$

in which $r=\sqrt{x^2+y^2+z^2}$, $M_x=\cos(\theta)$, $M_y=\sin(\phi)\sin(\theta)$, $M_z=\cos(\phi)\sin(\theta)$.

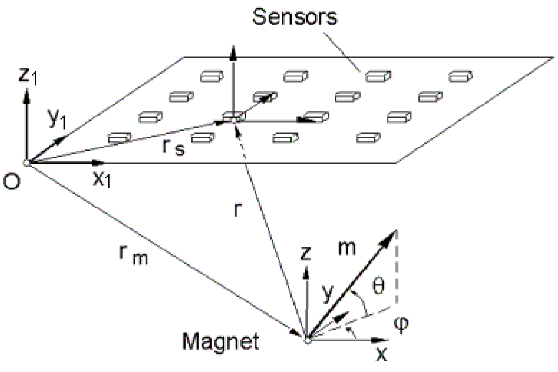


Fig.1 a vector of a magnetic dipole located at (x0, y0, z0)

Observe flux density $\vec{B}_m$ along one or more axis by sensors, the position and orientation of dipole were obtained by solving (3):

$$\vec{B}_m - \vec{B}_{cal} = 0 \tag{3}$$

As equation (2) consists of 6 unknown parameters, it can be solved with 6 equations. The solving method can be an iterative optimization algorithm: the probe's location and orientation are first presumed or guessed to be at a predicted location and orientation; then an iterative process is used to compare values of the magnetic field at the guessed values with the measured field values; If the two are close, the guessed values are presumed to be accurate; or nonlinear least squares fitting algorithm.

III. EXPERIMENT AND RESULTS

A. System Setup

The magnetic marker used in this study was a cylindrical permanent magnet with a dimension of $\phi\ 8\times 8mm$. The sensors used for measuring the magnetic field due to the marker are 4 hall sensors (Honeywell, SS495A). The distance between two sensors is 30mm. As the sensor's output is a voltage shift at 2.5 volts when the power supply is 5V, a DC shift circuit is applied before amplification, in order to avoid saturation.

A conventional data acquisition system, with a sampling frequency of 50Hz and 4 channels, converts the analogue amplified signal to digital and sent to a computer for further processing. The computer implements an iterative algorithm to recalculate the position of the magnet with respect to the sensor's array. The block diagram of the whole system is shown in Fig. 2.

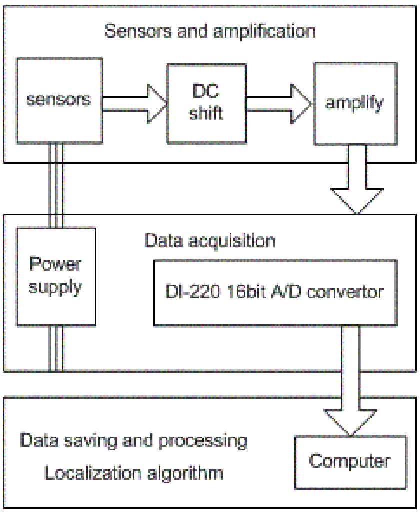


Fig. 2 Experiment setup block diagram

B. Procedures and Results

The experiments are carried out in an *unshielded* room, despite the influence of ambient magnetic field. As only 4 hall sensors are employed, the tracking is constrained to locations and the orientations are pre-determined as (0, 0, 1).

First, sensors calibration must be carried out to get the magnetic moment *m* and output amplification *k*. Place sensors on axis of the magnet at a known distance; record the sensors' output data, according to equation (2), we can get:

$$\overrightarrow{V_{mea}} / k = \frac{\mu_0}{2\pi} \times \frac{\vec{m}}{r^3} \tag{4}$$

then the value of *km:*

$$km = 2\pi r^3 \overrightarrow{V_{mea}} / \mu_0 \tag{5}$$

The calibration result is shown in table I.

After calibration, a second experiment is carried out to localize the magnet when it's immobile. Place the magnet at two different positions and calculate the coordinates using Levenberg-Marquardt optimization method [3], the results are shown in table II:

TABLE I
CALIBRATION RESULTS

	Sensor output	Overall output	Amplification
km	-8.4428	422.14	-50

TABLE II
IMMOBILE MARKER POSITIONS

First position	X	Y	Z
Calculated coordinate (mm)	-12.2631	-2.8174	-39.3991
Reference position (mm)	-15	-5	-41
Reference error (mm)	2.7369	2.1826	1.6009

Second position	X	Y	Z
Calculated coordinate (mm)	-4.1703	12.3381	-38.8170
Reference position (mm)	-5	15	-41
Reference error (mm)	0.8297	2.6619	2.1830

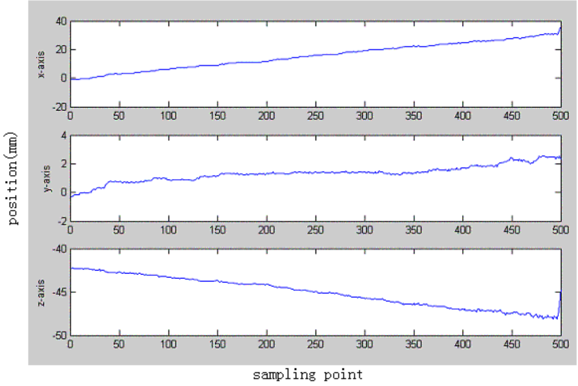
The calculated results are independent of x0, y0 of seed solution, but dependent on z0, because there're two symmetric solutions along the axis of dipole. But in actual use, it will not be a problem as the magnet is always on one side of the sensor array. The error includes both the calculated coordinate's error and the reference position errors. From table 2, we can see that the coordinate errors are around 2mm, which is not changing much with the actual positions, so the error percent will be decreased with the increase of the distance.

The experiments followed are to track the marker when it's moving along coordinate axis at a rate of 2mm/s. As shown in Fig. 3, (a) is along x-axis, (b) is along opposite of x-axis, (c) is along y-axis, and (d) is along opposite of y-axis. From Fig. 3, we can see that the moving distance of the marker is as long as 60mm (in (c)), and the coordinates of other two axis do not vary much. The average calculation time is about 50ms. If the sampling rate is lower than 20Hz, a real time tracking is possible.

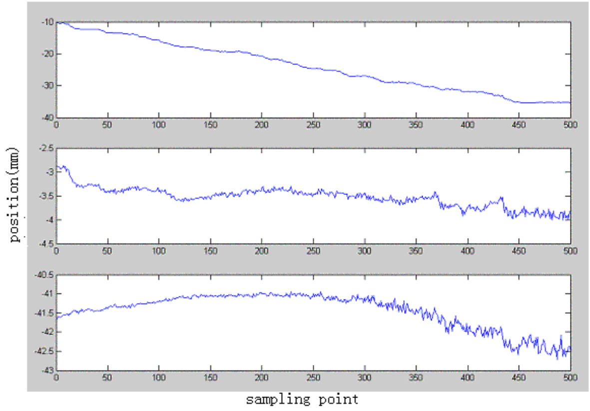
IV. DISCUSSION AND CONCLUSION

In this paper, a tracking system with 5 degrees of freedom has been analyzed and 3 dof tracking is realized by a 2-D array hall sensors. The experiments are carried out in an unshielded environment. Compared with sensors used in [4, 5], the one-axis hall sensors are ordinary and cheap, which will surely reduce the expenditure of the system. The results show the system is robust despite of the comparatively rough reference coordinates. As the magnetic marker is very small, it can be inserted into the capsule endoscope and tracked with array of hall sensors.

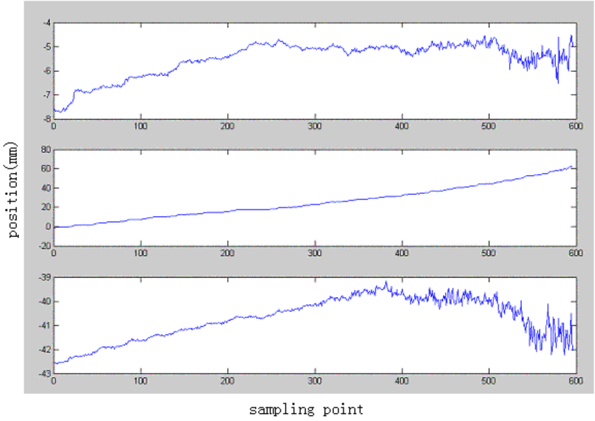
Because only 4-sensors are employed in this paper, x, y, z are determined in experiments. In the future study, more sensors will be added to the array and 5 parameters (x, y, z, θ and φ) will be all determined using this method. A more accurate coordinate system should be employed in later experiments, too.



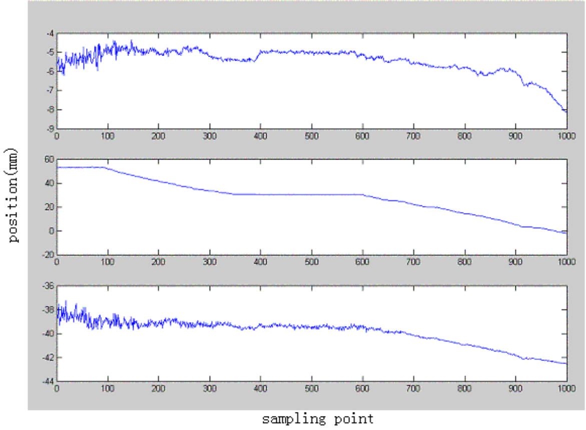
(a) Marker moving along x-axis



(b) Marker moving along opposite of x-axis



(c) Marker moving along y-axis



(d) Marker moving along opposite y-axis

Fig. 3 Marker positions when it's moving

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