Tracking and Orientation Modeling of Capsule Endoscope

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Abstract: - This paper proposed a capsule endoscope orientation evaluation method based on ultrasonic ranging and piecewise intestine modeling. An intestine coordinate system was introduced to evaluate the capsule orientation. The Matlab simulations allowing 10% variations on roll, pitch and yaw were found around 3°, 10° and 2° respectively. Average values on 10 trials were less than 0.4° for orientation angles. These values were good enough cover image processing, medication doping and specimen sampling.

Key-Words: - Capsule endoscope, Localization, Orientation, Ultrasonic, Tracking, Moving orientation

1 Introduction

Capsule endoscope addresses the diagnosis problem of small intestine disease [1-2]. The capsule endoscope can directly examine the entire gastrointestinal tract without pain. It observes the inside wall of the small intestine and transfers its pictures [3-5].

There has been a substantial amount of technical improvements to make a capsule endoscope complete. S. Pongnumkul et al. proposed an image reconfiguration method to change the video stream captured by the endoscope to the 2-D image to reduce the time required for diagnosis [5]. A position and orientation tracking of the capsule is needed for a precise diagnosis. It is hard to know the location of the endoscope image data only. The first commercial capsule endoscope, M2A, includes a localization method [6-7]. Most of them are based on the magnetic localization using the magnet enclosed in the capsule [6-8].

Researches on the capsule orientation are rare despite recent technical advances of capsule endoscope. The capsule orientation provides with basic information for specimen sampling, medical doping and image processing. Magnetic field is the basic phenomenon for the conventional orientation evaluation of the capsule. The orientation evaluation based on the magnetism experiences extreme difficulties finding the capsule orientation, especially the roll angle.

Conventional approaches do not account the intestine path. The changes in intestine orientation should be evaluated to get the capsule orientation.

This paper proposes a capsule orientation tracking scheme using ultrasonic waves. It measures the location of the capsule as well as its orientation. Travel time differences between an ultrasonic pulse and a RF pulse give distance data. The proposed orientation tracking technique addresses the precise location of the disease area using the distance data.

This paper is organized as follows. Section 2 describes the capsule tracking system based on ultrasonic sensors. Section 3 describes the methods to get the orientation of the intestine in a human body. Section 4 describes the methods for getting the angle reflecting the orientation of the capsule. Section 5 presents our experimental results. Section 6 concludes with evaluations.

2 Tracking System for Capsule Position

Due to continuous movement of the small intestine while digestion and absorption, we should know the correct intestine direction at the time of recording for precise diagnosis. We use ultrasound sensors to identify orientation of the intestine and capsule endoscope. The entire system architecture is shown in Fig. 1. The system consists of an onboard tracking module; a capsule endoscope, a binder system and a host computer.

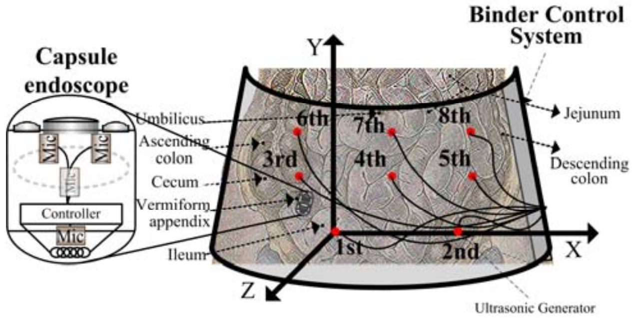

Fig. 1. The architecture of the capsule endoscope and the binder control system

The onboard tracking module senses the ultrasound from the binder system, and sends back the responses via a radio frequency. The binder system transmits the ultrasonic waves and also transfers the data from the capsule endoscope to the host computer. The binder calculates the distance between the generator in the binder system and the receiver in the capsule endoscope. It transfers this distance information to the computer. The host computer decides the 3-D position vector and the orientation of the capsule camera. It links this information to the captured images.

The three dimensional coordinate of the receiver is obtained though triangulation based on signals ultrasonic sensors as shown in the figure. The orientation of the capsule and its model are obtained from three coordinate values. Symbolic R1 through R4 represent ultrasonic transmitters and P is the origin.

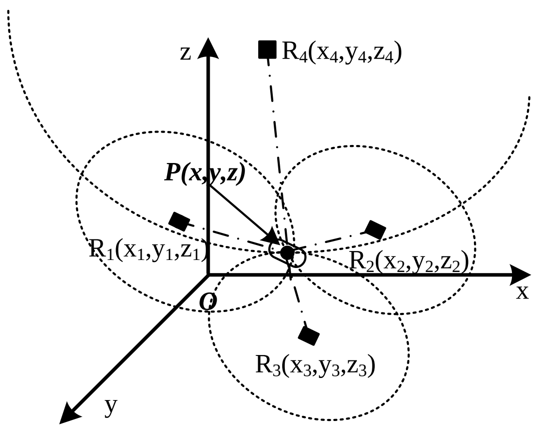

Fig. 2. A three dimensional ranging

3. Intestine Frame Modeling for the Orientation Measurement of the Capsule

We now turn to the modeling issues of the frame. The intestine frame provides with the reference frame for orientation evaluation. A reference frame is the basis of capsule orientation evaluation covering various capsule orientations as shown in Figure 3 without a reference frame. The capsule orientation may experience severe data degradation without a reference frame due to the changes in the intestine path, which is reflected on the intestine frame.

The intestine moves steadily and each person has different digestion pathway, it is not enough to identify precise orientation of the intestine problem only with the position of the endoscope. It means that we should know the intestine orientation and capsule orientation. Therefore, a reference-frame including information of the intestine orientation is needed. In this paper, we called the intestine-frame.

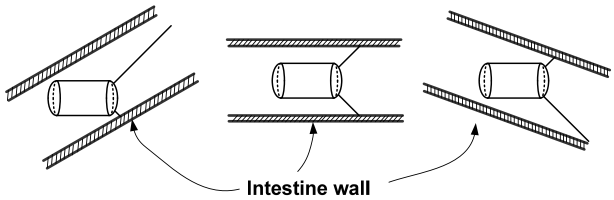

Fig. 3. Examples of diverse intestine direction

The capsule orientation changes along the digestion pathway and intestine movement. We consider each axis of the intestine-frame as a vector of the fixed-frame. We denote the axes l, m and n. As shown Eq. (1), all axes are fundamental vectors and orthogonal each other. The l, m and n axes become the same as the x, y and z axes of the fixed frame for the binder system when all the roll, pitch and yaw values for the intestine orientation are “o”. The roll, pitch and yaw values are represented based on the axes of the fixed frame.

$$\begin{aligned} &\vec{l}\cdot\vec{m} = \vec{m}\cdot\vec{n} = \vec{l}\cdot\vec{n} = 0 \\ &\left|\vec{l}\right| = \left|\vec{m}\right| = \left|\vec{n}\right| = 1 \end{aligned} \tag{1}$$

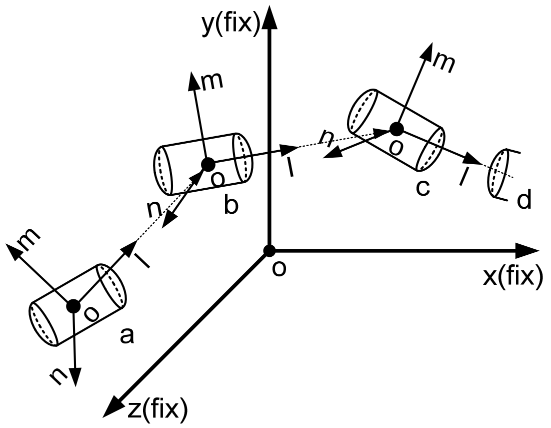

Fig. 4. A three dimensional location method using four receivers

We assume that the capsule moves to d by way of a, b and c consecutively, as shown in Fig. 4 We draw the capsule motion vector, l, from the measured coordinate information, as Eq. (2). The axes m and n can be drawn from the yaw and pitch. The yaw means the acute angle between the l-axis and the xy-plane, and the pitch is the acute angle between the l-axis and the xz-plane shown in Eq. (3).

$$\vec{l} = \begin{bmatrix} x_{pre} - x_{late} \\ y_{pre} - y_{late} \\ z_{pre} - z_{late} \\ 0 \end{bmatrix} \quad (2)$$

$$\begin{aligned} yaw &= \arctan(\overrightarrow{l(2)} / \overrightarrow{l(1)}) \\ pitch &= \arctan(\overrightarrow{l(1)} / \overrightarrow{l(3)}) \end{aligned} \quad (3)$$

$$Rot(n, yaw)^{-1} \times Rot(m, pitch)^{-1} \times \vec{l} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

$$\begin{aligned} &Inestine\ \ orientation = \\ &\quad Rot(n, yaw) \times Rot(m, pitch) \end{aligned} \quad (5)$$

We substitute the pitch and yaw for the Eq. (4) then get a unit vector as a result. Using this, we drew an equation, Eq. (5), which defines the m-axis and the n-axis. The entire intestine can be modeled with Eq. (5), which contains the yaw and the pitch, and the position information of the endoscope (P).

$$RPY_{intestine}(0, pitch, yaw) = \begin{bmatrix} l_x & m_x & n_x & P_x \\ l_y & m_y & n_y & P_y \\ l_z & m_z & n_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{aligned} l_x &= C\phi_{pitch} C\phi_{yaw} \\ l_y &= S\phi_{yaw} \\ l_z &= -S\phi_{pitch} C\phi_{yaw} \\ \\ m_x &= -S\phi_{yaw} C\phi_{pitch} \\ m_y &= C\phi_{yaw} \\ m_z &= C\phi_{pitch} S\phi_{yaw} \\ \\ n_x &= S\phi_{pitch} \\ n_y &= 0 \\ l_z &= C\phi_{pitch} \end{aligned} \quad (6)$$

The Eq. (6) is to find the capsule orientation values discussed in Chap 4. Here, “C” and “S” represent the sine and cosine operation, respectively. The “I” stands for the 4x4 unit matrix

4. Mathematic Model for the Capsule Orientation

The capsule orientation values are calculated based on the orientation of the piecewise intestine model. The relative geometry of the capsule and the piecewise intestine model are the core of the calculation. The capsule orientation calculation begins with the definition on a new frame for the capsule. The calculation algorithm takes signals from four receivers. Three of them are for capsule orientation calculation and the remaining one is to settle the origin point of receivers. Figure 5 shows a representation of the capsule orientation carrying the roll, yaw and pitch values.

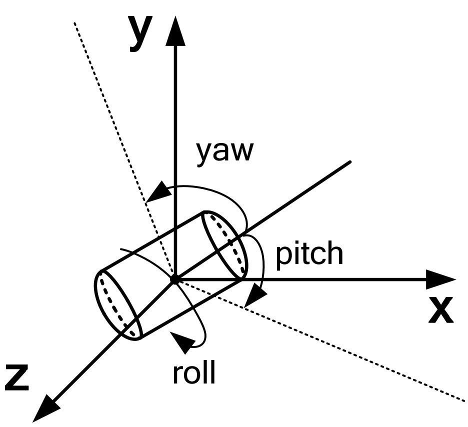

Fig. 5. Representation of the capsule orientation: roll, pitch, yaw

To measure the capsule orientation, we need a frame applying for the capsule. We define the frame as the capsule-frame. The capsule frame is from the position coordinates of ultrasonic receivers. Fig. 6 shows the three capsule ultrasonic receivers A, B and C. The coordinates of the three receivers yield two points exploiting Eq. (7). The origin point of the capsule frame is obtained using the coordinate values of another receiver. The o, p and q axes are the lines connecting the origin point and the A, B and C receivers, respectively.

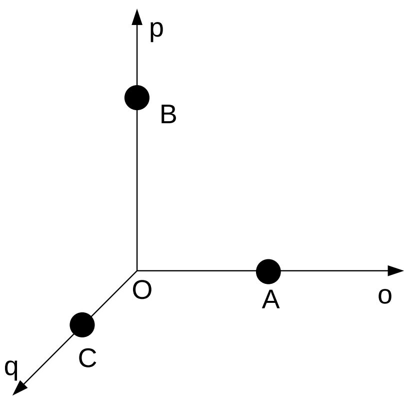

Fig. 6. The capsule frame definition

$$\vec{o} = \overrightarrow{OA} = (A_x - O_x, A_y - O_y, A_z - O_z)$$
$$\vec{p} = \overrightarrow{OB} = (B_x - O_x, B_y - O_y, B_z - O_z) \quad (7)$$
$$\vec{q} = \overrightarrow{OC} = (C_x - O_x, C_y - O_y, C_z - O_z)$$
$$\overrightarrow{OA} \cdot \overrightarrow{OB} = \overrightarrow{OA} \cdot \overrightarrow{OC} = \overrightarrow{OB} \cdot \overrightarrow{OC} = 0$$

The matrix RPY capsule represents the capsule frame on the fixed frame. Eq. (8) represents the capsule frame comprising the Euler's angle set (roll, pitch and yaw).

$$RPY_{capsule}(roll, pitch, yaw) = \begin{bmatrix} o_x & p_x & q_x & P_x \\ o_y & p_y & q_y & P_y \\ o_z & p_z & q_z & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$o_x = C\phi_{roll} C\phi_{pitch}$$
$$o_y = S\phi_{roll} C\phi_{pitch}$$
$$o_z = -S\phi_{pitch}$$

$$p_x = C\phi_{roll} S\phi_{pitch} S\phi_{yaw} - S\phi_{roll} C\phi_{yaw}$$
$$p_y = S\phi_{roll} S\phi_{pitch} S\phi_{yaw} + C\phi_{roll} C\phi_{yaw}$$
$$p_z = C\phi_{pitch} S\phi_{yaw}$$

$$q_x = C\phi_{roll} S\phi_{pitch} C\phi_{yaw} + S\phi_{roll} S\phi_{yaw}$$
$$q_y = S\phi_{roll} S\phi_{pitch} C\phi_{yaw} - C\phi_{roll} S\phi_{yaw}$$
$$q_z = C\phi_{pitch} C\phi_{yaw} \quad \textbf{(8)}$$

Components of the RPY capsule matrix are described as combinations of the capsule origin coordinate P and unit vectors o, p and q in the capsule frame. Calculation of the Euler's angle set requires a unit vector representation for the o, p and q axes. Eq.(7) yields the o, p and q vectors.

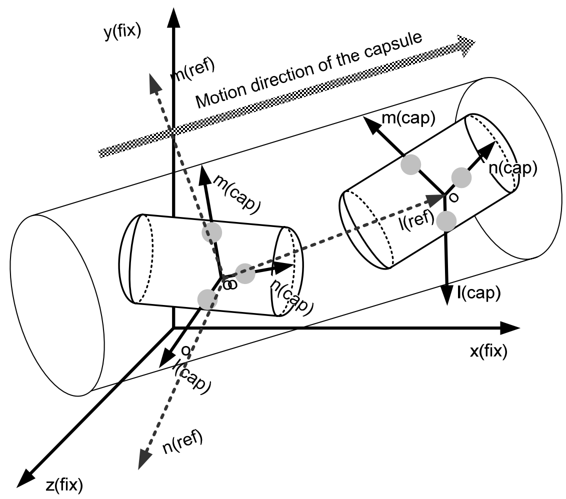

Fig. 7. Capsule orientation with the intestine frame

The capsule may have an arbitrary orientation within an intestine piece as shown in Fig.7. Eq.(7) gives the orientation values from the relationship between the fixed frame and the varying intestine frame.

$$RPY_{orientation}(roll, pitch, yaw) = RPY^{-1}_{intestine}(roll, pitch, yaw) \times RPY_{fixed}(roll, pitch, yaw) \quad (9)$$

The Euler angle set representing the capsule orientation is given in equations (10) through (12).

$$Roll = -\tan^{-1}\left(\frac{RPY_{capsule}[1,1]}{RPY_{capsule}[2,1]}\right) \quad (10)$$

$$Pitch = -\tan^{-1}\left(\frac{RPY_{capsule}[1,1]C(roll) + RPY_{capsule}[2,1]S(roll)}{RPY_{capsule}[3,1]}\right) \quad (13)$$

$$Yaw = -\tan^{-1}\left(\frac{RPY_{capsule}[2,2]C(roll) + RPY_{capsule}[1,2]S(roll)}{-RPY_{capsule}[3,2]C(roll) + RPY_{capsule}[3,1]S(roll)}\right) \quad (14)$$

5. Simulation Results

The simulation is to evaluate the proposed orientation tracking method. We use the Matlab simulator and a visual studio tool to measure the orientation of the capsule.

The input data for the simulation has the form of sine curves for roll, pitch and yaw values. The input for the intestine modeling also has the sine curve forms.

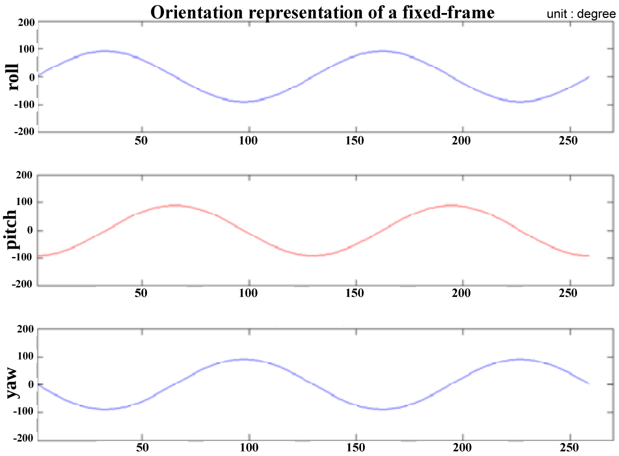

Fig. 8. Capsule orientation with the fixed-frame

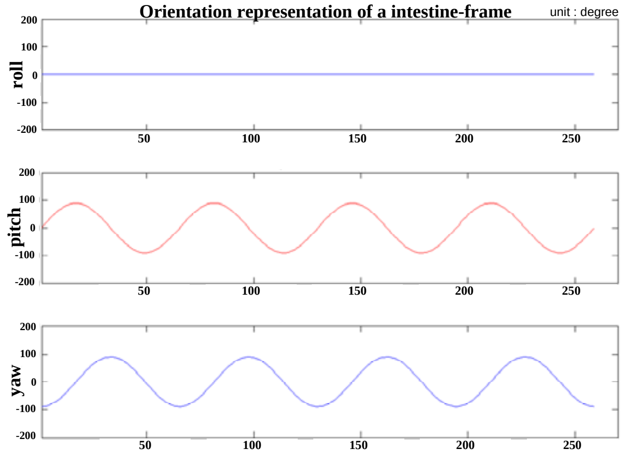

Fig.9. Intestine orientation with the intestine-frame

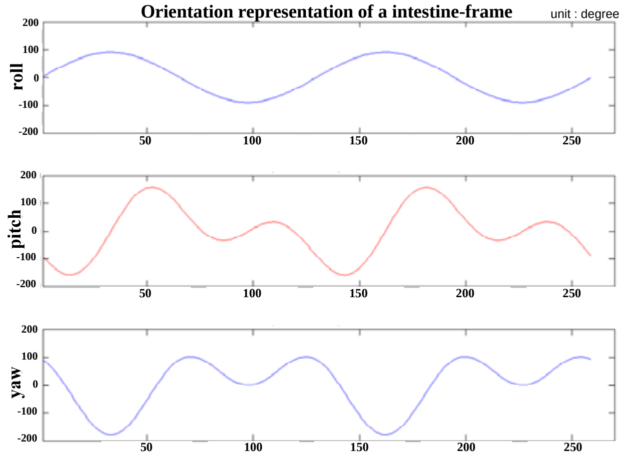

Fig. 10. Capsule orientation with intestine-frame

Figures 8 through 10 show the simulation results verifying the orientation evaluation algorithm. Figures 8 and 9 are based on the fixed coordinate of the external binder system. Figure 8 shows the absolute values of the roll, pitch and yaw angles of the capsule. Figure 9 illustrates the roll, pitch and yaw obtained from the intestine model. The capsule orientation within a body is shown in Figure 10.

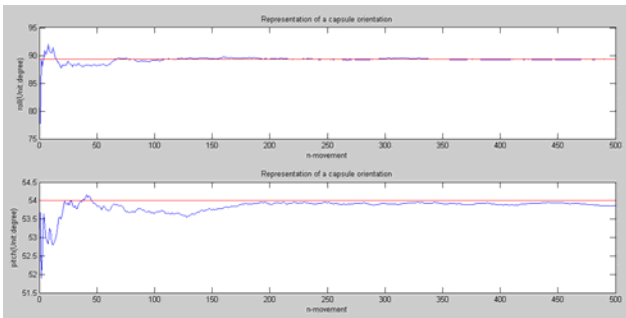

Fig. 11. Average value of the capsule orientation with error component

The simulation runs cover variations in ultrasonic signal propagation Figure 11 shows the simulation results reflecting the 10 % propagation speed variation. The variation free propagation yields the roll, pitch and yaw values of 0˚, 89.3˚ and 54˚, respectively. The maximum errors reflecting the 10% variations are 3˚, 10˚ and 2˚ for the roll, pitch and yaw, respectively. Average errors over 10 trials give the roll of 0.2˚, the pitch of 0.4˚ and the yaw of 0.2˚.

6. Conclusions and Discussion

This paper presents a scheme measuring the orientation of capsule endoscope using the intestine model in a human body. The coordinates system of capsule endoscope is moving orientation in a human body. Intestine model is supplied reasonable frame for measurement of real capsule orientation in a human body.

We measured roll, pitch, yaw of capsule endoscope orientation using a ultrasonic wave. The simulation runs have been performed on the mock-up seven times bigger than an actual capsule. The maximum measurement error for the capsule coordinates found 11.82, 18.13 and 1.75mm in the x, y and z direction, respectively. The maximum errors on roll, pitch and yaw values are about 3°, 10° and 2°, respectively. Repeated measurements reduce these errors less than 0.2°. The accurate location and orientation information help image enhancement on the intestine wall photos from the capsule camera, and thereby allow better diagnosis and precise release of medicines from capsules inside a human body.

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