ENHANCING ENDOSCOPIC IMAGE PERCEPTION USING A MAGNETIC LOCALIZATION SYSTEM

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Abstract

Localization and navigation of an endoscope within a patient’s body is usually based on anatomical landmarks recognized by the surgeon. However, this technique can be complicated when a long and flexible endoscope is used. The present study describes a novel system that provides longitudinal position and orientational stabilization of the endoscopic image using a miniature magnetic sensor located at the tip of a flexible endoscope. As a result, the surgeon’s perception of anatomical features is enhanced enabling accurate localization of the endoscope. To evaluate the performance of the proposed system and its applicability to clinical use, an in vivo experiment was performed in which surgeons used the system to perform neuroendoscopy surgery on a pig’s spinal cord.

Introduction

During endoscopic procedures navigation is usually based on anatomical landmarks within the endoscope image recognized by the surgeon. Different methods have been developed to assist the surgeon in deciphering the anatomical information since the small, usually distorted two-dimensional field of view is confusing to interpret. These methods include additional imaging modalities such as CT scanning [6], ultrasound [1-2] or MR images [3-5] that locate the endoscope tip, as well as intraoperative magnetic sensors, RF sensors [7] and optical tracking [8] that are used to localize the endoscope’s tip upon a virtual model of the working space. Since magnetic
localization systems have the useful advantages of not being disturbed by human tissues and of being safe for humans when used below a certain frequency and intensity [20], several have been developed and commercialized [9-19].

In this paper, we present a novel concept for endoscope navigation. This concept is based on the fact that streaming endoscopic visual information can be better utilized if it is combined with longitudinal information and has been corrected for the orientation of the endoscope tip to create a stabilized view. Such a combined system for endoscope navigation is proposed here. A magnetic sensor is presented that can be miniaturized and compacted within a 2.7 mm catheter’s head while maintaining three working channels. The miniature magnetic sensor is attached to a long and flexible endoscope and measures the endoscope’s longitudinal position and orientation. This information is used to display the image in a constant orientation regardless of the actual endoscope tip orientation. Thus, the surgeon sees an image with a fixed orientation that helps him recognize anatomical landmarks, and consequently the surgeon’s ability to identify accurately the endoscope’s location is enhanced. Summarily, the novel design presented here improves the surgeon’s perception of the endoscopic images of the working space.

Motivation

When a flexible endoscope is inserted into an elongated and relatively featureless space it is difficult to identify which part of the space is observed and almost impossible to navigate. For example, Figure 2 is an image of the spine’s subarachnoid space obtained by a Karl-Storz's flexible endoscope. If the endoscope’s orientation is not known and only visual data is supplied, then two images taken from positions A or B (Figure 1) of the subarachnoid space (Figure 2) seem almost identical.

One can observe that the arrows in Figure 1 that show the upper side of the image are different in angle. With the system presented in this investigation this rotation angle is measured by a magnetic sensor and when combined with the visual image provides an unambiguous location for the endoscope tip.
Figure 1: Illustration of the possible positions where the image in Figure 2 can be taken. The arrows present the ‘up’ direction of the image.

Figure 2: The image obtained with an endoscope in the spine’s subarachnoid space. The spinal cord is designated with ‘1’ and the dura mater designated with ‘2’.

System Description

The system consists of an imaging part and a sensing and localizing part as shown in Figure 3. The imaging part is a flexible φ0.4 mm fiber inserted into the central lumen (0.7 mm diameter) of a 2.3 mm catheter. The catheter has 8 additional lumens (0.45 mm diameter) for different actuation and intervention purposes.
Sensing and localization system of the endoscope

The sensing and localization system has two main components: the sensor at the tip of the catheter and the transmitter that creates the magnetic field.

Given a unidirectional magnetic field, the rotation angle of the sensor can be derived by decomposing the magnetic field vector into two orthogonal directions. Figure 4 illustrates this decomposition. Using the sensor signals, the sensor rotation angle ($\alpha$ in Figure 4) and its distance from the transmitter is derived. The distance data is used to indicate whether the tip of the endoscope is within the workspace area and to normalize the signals.
Figure 4: Cross section of the sensor, illustrating the magnetic receivers that detect the magnetic field vector created by the transmitters. Decomposition of the transmitters’ magnetic field ($B_o$) into the receiver coils ($B_{i1}$ and $B_{i2}$) derives $\alpha$ - the sensor's rotation angle.

The miniature sensor of 2.6 mm diameter and 6.5 mm length is attached to the catheter’s tip (see Figure 5). The sensing elements are 6 magnetic receivers, each a micro-coil of 0.7 mm diameter and 1.2 mm length (see Figure 6 and Figure 7). The micro-coils are arranged in three pairs orthogonal to each other while each pair is electrically connected in series. This micro-coils configuration increases the sensor signals without blocking many of the catheter’s lumens. The sensor has been designed so that only three lumens are blocked by the micro-coils. The main lumen and three additional small lumens going through the receiver sensor are still intact (see Figure 5).
Figure 5: The endoscope and the sensor receiver at the catheter’s tip: a - the localization sensor, b - the endoscope, c - the catheter.

Figure 6: The complete receiver sensor.
A transmitter that creates a uniform magnetic field over the workspace is placed along the back of the patient. The transmitter is a flexible strip of coils configured as 18 pairs of coils, placed along the spine (Figure 8). Each pair was designed to create a local uniform magnetic field over the target area (Figure 9).
Switching continuously between the transmitter pairs of coils creates a shift of the uniform magnetic field, which allows identification of the longitudinal position of the receiver, along the spine.

The images from the endoscope are captured by a PC through a video grabber card and then rotated according to the calculated rotation angle. As a result, the surgeon observes a constant orientation of the image with respect to the patient body, regardless of the actual rotation of the endoscope within the body.

**Steering the endoscope**

Steering of the flexible endoscope is described in detail in [1], and is basically achieved using a joystick, or a set of motors, which are connected to four pulling wires going through four lumens in the catheter. The wires are glued to the catheter’s tip. The distal part of the catheter is more flexible to enable steering by bending its tip (Figure 10). The remaining four catheter lumens are for the sensor electronic wires, for fluid injection to clear the viewed area of the endoscope, for drug delivery, or for electrode stimulation.
Sensor signal analysis

A PIC16f88 microchip creates a 1.6KHz square wave with a duty cycle of 88% for the transmitting coils. Each pair of coils in turn transmits a $25 \times 10^{-5}$T magnetic field for 2 cycles. The PIC’s A/D is used to sample the amplified sensor signals on both orthogonal coils, which are perpendicular to the catheter’s axis. Sampling begins 24µsec after each transmitter pair of coils begins transmitting when the signal reaches its maximum amplitude.

Since the transmitter coils are excited in sequence, the endoscope's tip longitudinal position is obtained by the time the closest transmitter pair transmits, which induces the maximal signal from the sensor.

The amplitudes ratio between the signals from two orthogonal sensor coils in the magnetic field provides a measure of the sensor’s rotation degree.
Experimental validation of endoscope’s rotation sensor

It was noted that the sensor micro-coils were not perfectly orthogonal and so this was taken into account in the inducted voltage measurement, for each sensor coil.

In order to calculate the rotation angle, it was assumed that the magnetic field generated by the transmitter was uniform in direction over the target area of the localization system. To verify whether this assumption was accurate, the magnetic field was measured with the micro-coils within the target area. At each location, the sensor signal was measured every 15° rotation. The coordinate systems origin was at the base of the transmitter pair of coils on the symmetry line between the two coils. \( x \) direction is on the line that connects the centers of the two coils, \( z \) is the symmetry line of the coils axes and \( y \) direction is along the transmitter pairs of coils. Figure 11 illustrates the readout of the micro-coils between 0° and 75° in different positions.

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\text{induced micro coils voltage}
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Figure 11: Readout of the micro-coils; pair 1 values (diamond), and pair 2 values (cross) in different positions: \([x, y, z] = [0, 0, 4] \) (solid line), \([x, y, z] = [0, 0, 6] \) (dashed line) and \([x, y, z] = [0, 0, 8] \) (dotted line). (values are in cm)

Figure 12 illustrates the measured angle versus the actual one at different distances from the transmitter coils, which gives an error of less than 6° in the rotation angle.
Figure 12: Comparing the measured rotation angle to the actual rotation of the sensor at the target area, 4 cm (diamond), 6 cm (square), and 8 cm (triangle) from the transmitter.

In vivo experimental analysis of system

An in vivo experiment was conducted on an anesthetized pig at the animal laboratory of the Faculty of Medicine at the Technion, Haifa, Israel. This experiment was approved by the ethical committee for experiments in animals of the Technion – Israel Institute of Technology (Approval No IL-019-02-2005).

After full anaesthetizing of the pig and under sedation and control ventilation, a small incision was made in the area of the pig lumbar spine. Laminectomy of L4 lamina was performed and the dural sac was exposed.

Initially, the position of the transmitters was calibrated by placing on the back of the pig a strip of ball markers with the same shape as that of the transmitter strip. The calibration strip was observed on an X-ray image relative to the spine vertebrae (Figure 14 lower image). Since the calibration strip is the same size as the transmitter strip, with identical distances between pairs of coils as between ball markers, placing the transmitter strip at the same position as the calibration strip gives the relations...
between the position of the pairs of coils and the vertebrae. The catheter insertion in the pig spinal subarachnoid space was performed through a small opening in the exposed dura under magnification. This was done manually, without the navigation joystick, which was not tested during this experiment (Figure 13).

Figure 13: The in vivo experiment conducted on an anesthetized pig spine.

The Graphical User Interface (GUI) shows (Figure 14 upper images) the real image received by the endoscope next to the rotated image, which is kept stabilized regardless of the actual rotation of the catheter and the endoscope.

The marks on the blue circle surrounding the rotated image indicates the steering directions right and left relative to the stabilized image; these directions change their location according to the rotation of the catheter.

The white rectangle (Figure 14 lower image) which is located near the ball markers represents the position of the sensor at the catheter’s tip. The exact longitude position of the tip has an accuracy of 25 mm, which is the distance between two sequential coils.
Figure 14: The GUI shows the real image (upper left) received by the endoscope and the rotated image (upper right) surrounded by a blue circle that indicates the position of the right and left navigation pulling wires. The lower image shows an X-ray of the spine with a white rectangle, which indicates the longitudinal position of the endoscope’s tip.

During the experiment the longitudinal position was measured accurately. Figure 14 indicates the catheter’s tip at position 3, which means the tip was below the third pair of coils. At that point an X-ray image was taken which verified that reading (Figure 15).
Conclusions

A novel localization system that enhances navigation during spine endoscopy is presented in this report. The localization system, which consists of an externally placed strip of transmitter coils in addition to miniature receiver coils positioned at the catheter tip, was built and tested \textit{in vivo} in the subarachnoid space of a pig spine. The experimental results indicate the ability of the surgeon to locate the catheter tip unambiguously along the whole spine even when a long and flexible endoscope is used. Thus, the fusion of visual sensing, provided by an endoscope, with a relatively simple orientation and positional sensor enables the surgeon to navigate safely within a featureless elongated medium such as the spinal canal.

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References


