

Registration for Image Integration of Intraoperative MRI and Endoscope, using MRI-compatible Manipulator

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Abstract: This paper is the first discussion on the registration of intraoperative MRI (Magnetic Resonance Imaging) and endoscope using Northern Digital Inc's Polaris (spatial measurement system) and MRI-compatible endoscope manipulator, to provide surgeon with real-time feedback of MRI to endoscope. In this paper, we have tested the accuracy of the registrations, using MRI-Endoscope-visible phantom whose geometry was known. Totally 3 different registration routes were tested. In the most accurate one, the phantom and endoscope were registered inside MRI-gantry. This had 0.4mm average and 1.0mm maximum error, but was supposed to be difficult, because the measurement inside narrow MRI-gantry was limited. In the worst accurate one, the endoscope-manipulator and phantom-bed were registered preoperatively outside MRI, and bed-manipulator was registered intraoperatively outside MRI. This had 2.9mm average and 4.1mm maximum error, but had better flexibility of measurement.

Keywords: Surgical Manipulators, Intraoperative MRI, MRI-compatible manipulator, MRI-compatible endoscope, Registration

1 Purpose

MRI can provide with fine and wide tomography of body tissue noninvasively. Its merits are non X-ray exposure, excellent soft tissue discrimination, and functional imaging like temperature mapping. Intraoperative MRI has been developed rapidly and widely, for surgeon to comprehend the anatomical structures behind the surface and changes caused by operation during surgery (Jolesz and Blumenfeld, 1994). For this usage, open MRI, which has a wide opening, has been available recently.

An endoscope has been popular in Minimally Invasive Surgery due to its less-invasive, real-time, bright and fine observations in body cavity. However, because its view is so limited, it's difficult to know the surrounding structures. Therefore it is clinically significant that the intraoperative tomography of MRI visualize the structures behind the narrow approach in an endoscopic surgery.

The combination of endoscope and MRI raises problems of MRI-compatibility and manipulation of endoscope inside MRI-gantry. MRI detects weak radio wave excited by strong radio wave in precise and strong magnetic field. Therefore the conventional endoscope might cause artifact and noise on MRI for lack of electromagnetic compatibility to MRI (Jolesz et al., 1998). The

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MRI-gantry is surrounded by magnets so closely as to keep strong magnetic field. Therefore it's difficult for the surgeon to manipulate an endoscope inside MRI-gantry. For these problems, we have studied MRI-compatible endoscope and MRI-compatible endoscope manipulator (Koseki et al., 2002).

The image capture and pan and tilt are not sufficient for image integration. It is helpful for effective navigation where the point viewed in endoscope is located in MRI, and where the point viewed in MRI is located in endoscope. In other words, the registration in MRI and endoscope is necessary.

In this paper, we would discuss registration for image integration of intraoperative MRI and endoscope, using MRI-compatible endoscope manipulator. Here tested 3 registration routes, which were different in the difficulties of measurement. The accuracy of each registration route was examined preclinically using a MRI-endoscope visible phantom whose geometry was known.

2 Materials & Methods

2.1 Outline

This MRI-Endoscope image integration was targeted for a transnasal neurosurgery, where a surgeon resects pituitary tumor inside skull through naris (Griffith and Veerapen, 1987). In this surgery, the surgeon's view was so limited by nasal cavity that it's difficult to see the surrounding structures. Therefore MRI was expected to facilitate these difficulties by providing with wide tomography. Major operations like incision into skull are performed outside MRI-gantry. When MRI needed, the patient is carried into MRI-gantry mounted on the top plate of surgical bed. Therefore, the endoscope manipulator is mounted on the top plate and can move with the patient. When the manipulator is not needed, it can be moved separately. Since the MRI-gantry is narrow, the endoscope is inserted into the patient's naris and mounted on the end of manipulator outside of MRI-gantry.

2.2 Registration Routes

To do registration in minimum steps, there were two answers, the endoscope measure a coordinate of an object which is known in MRI's coordinate system, or MRI measures a coordinate of an object which is known in the endoscope's coordinate system. In the former case, it's difficult to put an object inside nasal cavity, which is large enough to be identified its coordinate in MRI. In the latter case, MRI can not precisely measure coordinate of an object which is put on the periphery of imaging area as far as outside components of endoscope. For these reasons, a registration with a spatial measurement system was tested in this paper instead of registration in minimum steps. A spatial measurement system, Northern Digital Inc's Polaris has been the most common in image-guided surgeries.

Since Polaris can optically measure spatial coordinate of a reflective marker, it has wide measurement space, but it can not measure a marker behind obstacle. Therefore, the measurement difficulty increased as the marker is set deeper inside the narrow MRI-gantry. In this paper it's not discussed how difficult it is, because it much depends on clinical environment. However, just in case the measurement inside MRI-gantry is impossible, we would additionally test a method to know the patient's coordinate from outside MRI-gantry. It measures an outside part of the bed and calculates the patient's coordinate based on preliminary geometrical relationship between the part of bed and the patient.

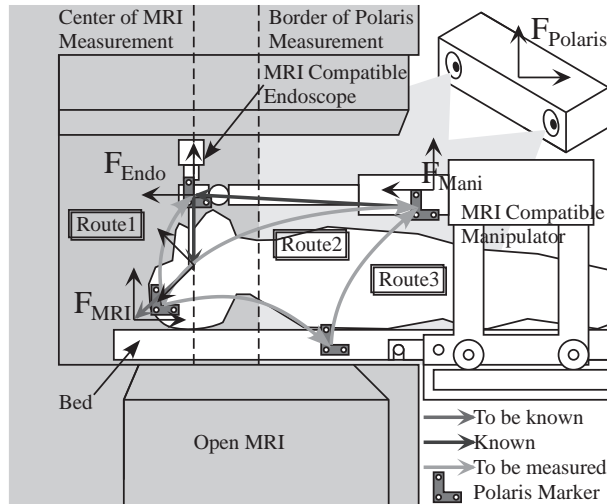


Figure 1 Registration Routes

Fig. 1 shows related coordinate systems and 3 registration routes.

Route 1: Patient-Endoscope: Polaris measures a MRI-visible marker (MRI-Polaris hybrid marker, mentioned later) attached on the patient, and a normal marker attached on the endoscope. This route is expected to have the best accuracy of these 3 routes, because it's the shortest and has less error factors. However, the measurement difficulty of the endoscope and patient inside MRI-gantry remains.

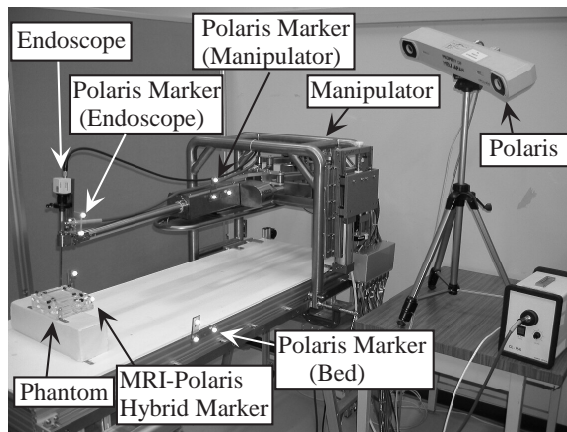
Route 2: Patient-Manipulator-Endoscope: Polaris measures a MRI-visible marker attached on the patient and a normal marker attached on the endoscope manipulator. The coordinate of the endoscope referring to the manipulator's coordinate system is known by its kinematics identified in preliminary Polaris measurement. The error of this route will increase in comparison to *Route 1* corresponding to the positioning error of the manipulator. The measurement difficulty of the endoscope inside MRI-gantry will be solved but that of the patient remains.

Route 3: Patient-Bed-Manipulator-Endoscope: Polaris measures a normal Polaris marker attached on the bed and the endoscope manipulator. The coordinate of the endoscope referring to the manipulator's coordinate system is known by its kinematics identified in preliminary Polaris measurement. The coordinate of the patient referring to the bed's coordinate system is known by Polaris measurement before the patient is carried into the gantry. The error of this route will increase in comparison to *Route 2* corresponding to the measurement error of the patient and the bed. On the other hand, the measurement difficulty inside MRI-gantry will be solved entirely.

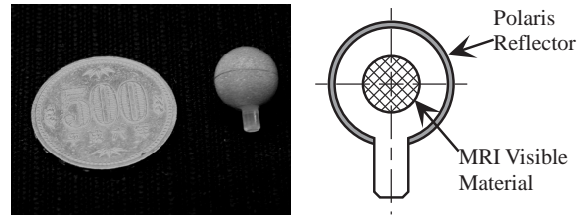
2.3 Registration System

Fig. 2 shows the MRI-endoscope image registration system, excluding MRI.

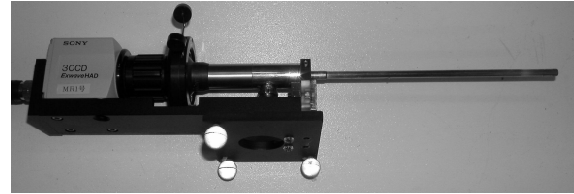
MRI: An open MRI, AIRIS-II (Hitachi Medical Corp., Tokyo, Japan) has been used for the targeted transnasal neurosurgery, and the endoscope manipulator was designed for this MRI. However, Siemens's Magnetom Impact Expert (1.0T) was used off-line due to the management



Registration system overview



MRI-Polaris hybrid marker



MRI-compatible endoscope setup

Figure 2 Registration system

of MRI. In this study, because MRI was just used to know the centums of markers, this replacement would never go against the purpose of this study.

Spatial Measurement System: Polaris (Northern Digital Inc., accuracy: RMS 0.35mm) was used to identify unknown coordinate. Polaris can simultaneously measure spatial coordinates of multiple targets optically. To identify the transformation between MRI and Polaris coordinate systems, the marker has to be recognized by both MRI and Polaris. MRI-Polaris hybrid markers were made for this purpose. MRI visible medium was enclosed at the center of a reflection sphere, corresponding to passive marker of Polaris.

MRI-Compatible Endoscope: An MRI-Compatible endoscope, which we have studied, was used. This endoscope was composed of non-magnetic material, and its camera unit was verified of electro magnetic compatibility to MRI. This endoscope had a conventional relay lens system, but the outermost thin metal cylinder was removed to reduce the artifact to MRI. This endoscope is attached with normal Polaris passive markers at known positions.

This endoscope was calibrated. Here was assumed that radial distortion occurred to the camera image, and the image was corrected by polynomial function of the radius. The parameters under calibration were the position of focal point, intersection position between optical axis and projection plane, its twisting angle, polynomial coefficient until 3rd order, aspect ratio of pixel. Grid points, whose coordinates were known referring to the mechanical coordinate system of the endoscope, were measured on endoscopic view. Then the parameters were numerically found to minimize the difference between real grid points and model-based grid points.

MRI-Compatible Endoscope Manipulator: An MRI-compatible endoscope manipulator, which we have studied, was used. This manipulator is composed of non-magnetic material, and its electric components were verified of electro magnetic compatibility to MRI. It can change the position and orientation of the endoscope inserted in nasal cavity, on 3 translational degrees of freedom (z -axis = vertical, y -axis = longitudinal) and 3 rotational degrees of freedom.

2.4 Accuracy Tests of Registration

MRI-Endoscope Visible Phantom: MRI-Endoscope visible phantom whose geometry was known was used instead of a patient for accuracy tests. The line of the endoscopic view, which

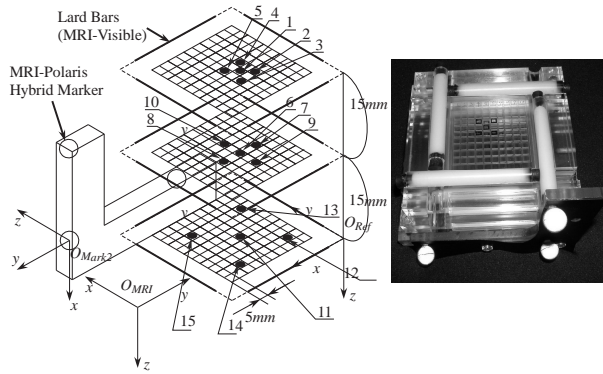


Figure 3 MRI-Endoscope visible phantom

Table 1 Length of 4 sides of the square formed by grooves [mm]

Side 1	Side 2	Side 3	Side 4	Average	Designed Value	Standard Deviation
69.7	70.8	69.6	69.5	69.9	70.0	0.6

was the line between focal point and point of gaze were transformed into the coordinate system of MRI by the proposed registration. On the other hand, the point of gaze on the phantom was known in the coordinate system of MRI. Therefore the accuracy was defined as the distance between the point of gaze and the line of the endoscopic view transformed by the proposed registration.

As Fig. 3 shows, the phantom was composed of 3 acrylic plastic plates that could be stacked precisely. A grid, which is visible to endoscope, was notched on each plate. Semicircular grooves were cut precisely around the grid, and cylinders filled with lard were set in the grooves. Because the lard cylinders were visible to MRI, the grooves in the coordinate system of MRI were known. The grid in the coordinate system of MRI could be known by designed geometrical relationship between the groove and grid. As indicated in Fig. 3, 5 grid points for each plate, totally 15 were chosen for points of gaze for one position of the endoscope. Totally the endoscope was positioned at 5 points.

3 Results & Discussion

Table 1 shows the length of 4 sides of the square formed by the grooves in MRI, whose designed value was 70.0mm. Since the average of 4 sides was so close to designed value, that the scale of MRI was precise. On the other hand, the standard deviation shows that MRI had 0.6mm error.

Fig. 4 shows the errors of 3 registration routes. They were 75 results of 15 grid points of the phantom by 5 positions of the endoscope. *Route 1* (Phantom-Endoscope) had the best accuracy of 3 routes, Ave. 0.4mm and Max. 1.0mm. Since the error was comparable to the sum of Polaris error (RMS 0.35mm) and MRI error (0.6mm), they were the major error factors of this registration. As for *Route 2* (Phantom-Manipulator-Endoscope), the error (Ave. 2.0mm and Max. 3.4mm) changed when the position of the endoscope changed. It meant the positioning error of the manipulator was dominant. In case that the error increased as the grid point was far, the rotational positioning error might be large. As for *Route 3* (Phantom-Bed-Manipulator-Endoscope), the error (Ave. 2.9mm and Max. 4.1mm) was worse than *Route 2* corresponding to indirect measurement of the patient.

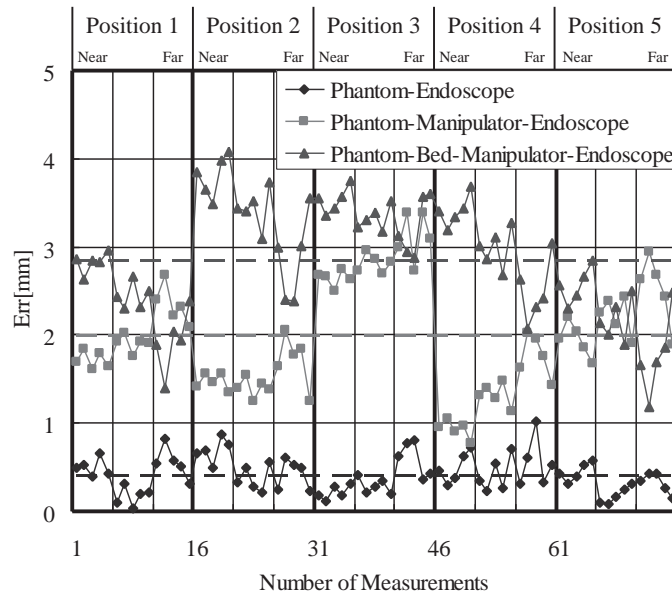


Figure 4 Error of 3 Registrations

4 Conclusions

In this paper, we discussed the registration for image integration of intraoperative MRI and endoscope using Polaris and MRI-compatible endoscope manipulator. Here tested 3 registration routes, which were different in the difficulties of measurement. The accuracy of each registration route was examined preclinically using a MRI-endoscope visible phantom whose geometry was known. The experiments showed that the shortest route had the least error of Ave. 0.4mm and Max. 1.0mm. The middle route had the error of Ave. 2.0mm and Max. 3.4mm. The longest route had the worst error of Ave. 2.9mm and Max. 4.1mm. These results were technically significant to discuss the trade-off between the accuracy and difficulties of registration inside intraoperative MRI.

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