A 3D Navigation System for Endoscopic Sinus Surgery

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Abstract

This paper presents a 3D image guided navigation system for endoscopic sinus surgery for the treatment of paranasal sinusitis. Endoscopic surgery is becoming more popular because of its low invasiveness, though, it has a problem of disorientation which is one of the hardest barriers for a novice and which may lead even an expert to serious surgical accidents such as CSF leakage and blindness. To prevent such complications and improve training process, the system shows 3D images of the patient and the endoscope with a *view cone* that indicates its viewing direction and viewing field in real time. It also has three clipping planes which automatically follow the endoscope and help the surgeon understanding its position. An experiment was conducted to evaluate the effectiveness of the system and many suggestions for improvement have been obtained.

Keywords: Endoscopic Sinus Surgery, Computer Assisted Surgery, 3D Navigation, Virtual Reality.

1. Introduction

1.1. Background

Endoscopic surgery is getting more widely used because of its low invasiveness. Especially in chronic sinusitis therapy, endoscopic surgery is much less invasive compared to conventional procedures. For example, conventional Caldwell-Luc operation opens into the maxillary sinus by incising into the supradental fossa opposite the premolar teeth. In this procedure, blood loss, pain when under local anesthesia and postoperative swollen cheek are well known problems.

In contrast, endoscopic sinus surgery is performed through nostril without any incision of gingival mucosa. The endoscopic surgery only opens ostium of maxillary sinus to facilitate drainage by resecting mucous membrane and by removing small pieces of thin bones with punch forceps under the endoscope. (For more detail on endoscopic surgery, please refer to [Yama88], [Rice93], and [Ashi95].)

Disorientation is one of the largest problems with endoscopic surgery. Though it is most important to understand where and what is seen on the endoscope screen, it is not at all an easy task, since nasal cavity is very narrow and its inside mucosal structures are very complicated. Not only a novice, but even an expert can get disoriented, which may lead to such serious surgical accidents as damaging optic nerve, eyeball, skull base, and brain; as Fig. 1 shows, nasal cavity and paranasal sinuses are located just medial to orbit and inferior to skull base.

This anatomical relation means the high risks of visual disturbances and neurological complications. Actually, CSF leakage and loss of sight are the two major complications of endoscopic sinus surgery. To increase the safety of endoscopic surgery and the effectiveness of its training, a good navigation system is strongly needed.

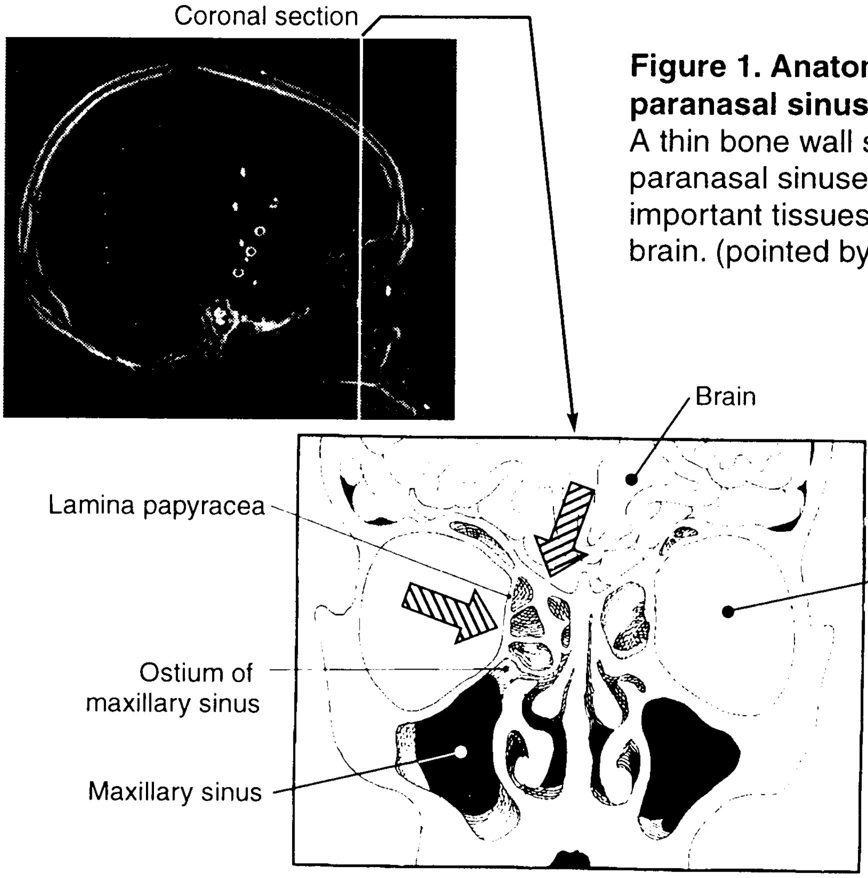

Figure 1. Anatomy of the paranasal sinuses
A thin bone wall separates paranasal sinuses and such important tissues as an eye and brain. (pointed by arrows)

[Rice93] P.21

1.2. Why does disorientation happen?

Disorientation with an endoscope is caused by several reasons:

(1) The position of endoscope's tip is hard to know, since the endoscope, which is 20 cm or longer, is deeply inside of the patient's body. Surgeons guess the location just by the inserted length and the orientation of the endoscope.

(2) Viewing direction of endoscope varies from 0 degree (straight viewing), 30 degrees, 70 degrees (forward oblique viewing), 90 degrees (lateral viewing), to 120 degrees (backward viewing) as shown in Fig. 2. Surgeons select and change endoscopes of different viewing directions during surgery. In addition, an endoscope rotates around its axis to obtain optimal surgical views (Fig. 3). Therefore, viewing direction more than zero causes strong disorientation. Even when the tip of the endoscope is visible, it is often difficult to understand where or what is seen on the screen of an endoscope.

(3) The view of endoscope is limited, magnified, and distorted. Confusion of landmarks must be expected. When blood or pus breaks out, the view will be completely lost.

(4) Within patient's body, a surgeon locates the endoscope position by finding landmarks, however, landmarks are often indistinguishable when being damaged by disease or injury due to previous surgeries.

(5) Endoscope manipulation is difficult, since nasal cavity is very narrow and the tip of the endoscope may easily encounter mucosa, especially when its viewing direction is more than

zero degree. Intensive training courses are indispensable.

1.3. Review of Existent Navigation Systems for Endoscopic Surgery

Currently, two image guided surgical navigation systems are commercially available; one is Viewing Wand by ISG Inc., Canada [Anon94][Roth95] and the other is InstaTrak system [Fried95] by Visualization Technology, Inc., U.S.A. The former uses a mechanical arm type 6 DOF probe, the Viewing Wand, to measure the position. The latter uses an electromagnetic sensor of 6 DOF attached to an aspirator, which works as a probe.

[Klimek96] reports another system which has been developed at Achen University Hospital. At first, it had mechanical probe, which has been substituted by optical one with tracking mechanism of the patient's head motion.

Each system shows the position of the probe's tip as crosshairs superimposed on triplanar display of the patient's CT images (Fig. 4). The Viewing Wand system can also show a 3D image reconstructed from CT images prior to the surgery.

These three systems are primarily used to prevent complications during surgery by localizing landmarks and important tissues such as optic nerve.

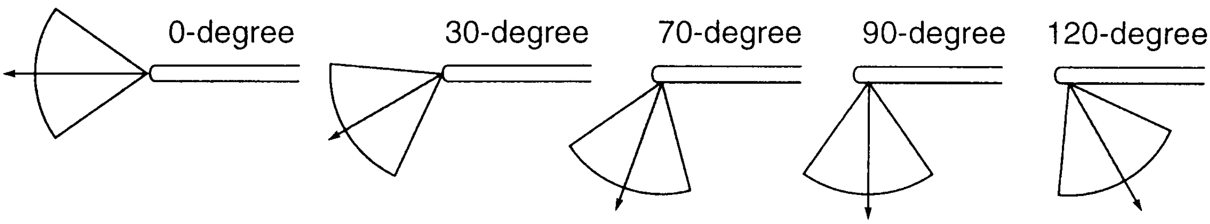

Figure 2. Viewing directions of endoscopes

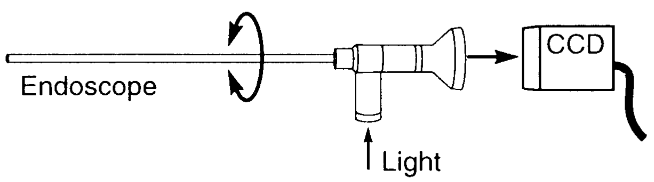

Figure 3. Endoscope configuration
Endoscope is attached to a CCD camera and can rotate independently.

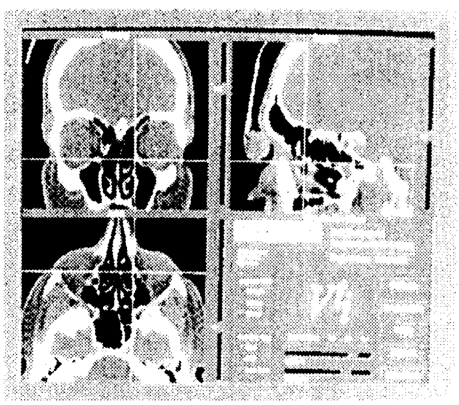

Figure 4. Triplaner display and crosshair cursor of InstaTrak system

1.4. The Scope of This Paper

The existent navigation systems lack information on an endoscope itself, such as its viewing direction during surgery, which are supposed to be major reasons of disorientation as described in **1.2** (2). The information is expected to be important especially in the training process of endoscopic surgery. Another problem is that triplaner display basically is 2D expression from which surgeons need to reconstruct 3D structure, which is a considerable mental load. Recent CG (computer graphics) and VR (virtual reality) technology can provide better 3D expressions which is expected to improve the understanding of 3D structure.

From this stand point of view, we have been developing a navigation system that focuses on endoscope. The system tracks endoscope and shows 3D image of endoscope, it's field of view, and patient's head in real time. An experiment was also conducted to evaluate the usability of the system for novice users. In the rest of this paper, the navigation system will be introduced in chapter 2. Chapter 3 describes the experiment, chapter 4 discusses the results and future work, then chapter 5 concludes the paper.

2. A Navigation System for Endoscopic Sinus Surgery

2.1. System Overview

Fig. 5 shows the navigation system configuration. The system consists of electromagnetic sensors of 6 DOF (Polhemus FASTRAK) attached to endoscopes of different viewing directions, and a graphic workstation (SGI). A sensor is fixed on an endoscope with a mount made of acrylic resin (Fig. 6) to lessen the noise of the endoscope's metal parts. It measures the position and direction data of the endoscope, which are sent to a graphic workstation (SGI Onyx) over the Ethernet. The view of the endoscope is shown on the monitor.

Fig. 7 is the dummy skull to interact with endoscopes. It was made by Laser Lithography from CT images of a real patient, was colored to prevent too much reflection of endoscope's light, and was fixed on an wooden table. It has a white "external nose" to restrict the freedom of the endoscope operation.

2.2. Navigation Software

The navigation software is written in C with OpenGL. On the navigation monitor, it shows:

(1) A 3D image of the patient's head. Both skin and skull are shown, which were polygonized from CT images by Marching-Cube method using Visualization Toolkit [VTK96]. It was carefully calibrated with the real dummy skull model.

(2) A virtual endoscope with a "viewing cone" (Fig. 8) and light. A viewing cone is a new way to show the viewing field of an endoscope three dimensionally. Its axis and angle are identical to the viewing direction and the angle of visual field of the endoscope, respectively. It also has a spot light to the viewing direction, just as the real endoscope does. A virtual endoscope precisely follows the movement of the real endoscope.

(3) Clipping planes. The system has three orthogonal clipping planes (Coronal, Sagittal, and Horizontal/Axial) which can be moved independently and can be used in any combination. Only the patient's head can be clipped; the clipped part is shown in transparent color (Fig. 9) and the transparency can be altered from 0% (opaque) to 100% (invisible). Clipping planes can be set to auto-tracing mode, in which clipping planes follow the tip of the endoscope.

2.3. Procedure and Results

The navigation procedure is as follows:

(1) Take CT slice images of a patient and convert them into 3D polygonal data.

(2) Calibrate patient's head with the 3D polygonal data on the graphic workstation using a 3D sensor. Anatomically distinguishable points, such as ear holes, are used in calibration. Currently, a dummy skull is used instead of a real patient.

(3) Operate endoscope. In addition to endoscopic view, current position and rotation of the endoscope is drawn on the navigation monitor screen as a virtual endoscope with viewing

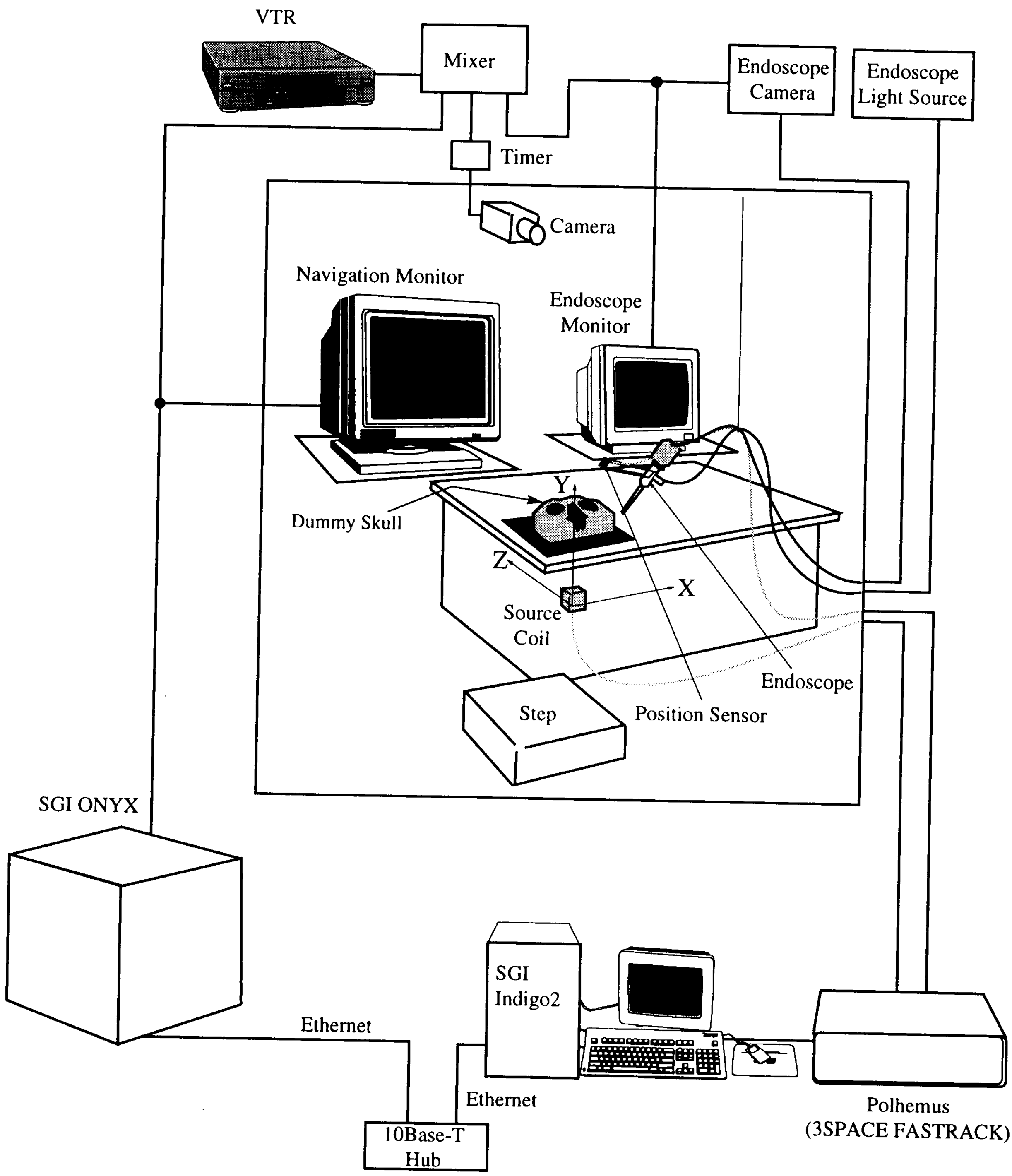

Figure 5. Navigation System Configuration

cone. When cutting planes are active, the 3D model of the patient's head is shown in transparent color so that the inside of the patient's body can be seen much clearer.

With SGI Onyx RE2 (4 CPU), a model of over 30,000 polygons could be navigated in 5-10 Hz graphics refreshing rate depending on the number of active clipping planes. The bottleneck is obviously the memory transferring time of polygon data. Reducing the number of polygons without losing the detail and more efficient polygon data structure is needed.
The effect of viewing cone, endoscope light, and auto-tracing clipping planes is remarkable. Without tracking mechanism of the surgeon's head nor 3D displaying device, auto-tracing clipping planes can give very good understandings of 3D space information. The simulated light of the virtual endoscope shows the distance to walls by brightness that changes in real time. And the system enables, so to speak, instrument flying; a user can catch a landmark into the view of the real endoscope without seeing endoscope's monitor, but just by catching it within the viewing cone of the virtual endoscope on the navigation display.

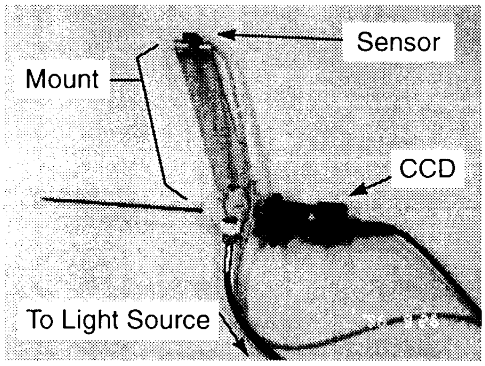

Figure 6. An electromagnetic sensor attached to an endoscope

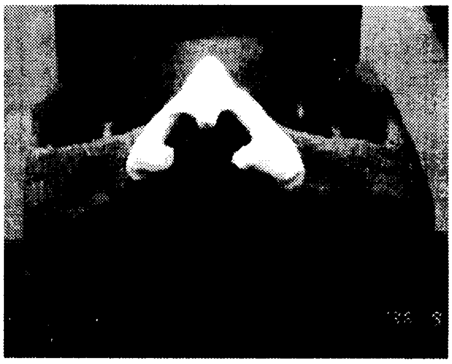

Figure 7. The dummy skull made by Laser Lithography

Figure 8. A virtual endoscope with viewing cone
The viewing cone shows the viewing direction and angle of visual field of the endoscope.

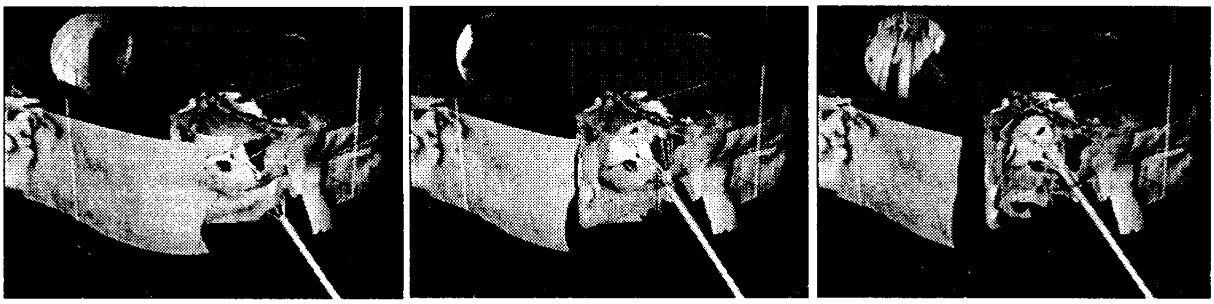

Figure 9. Auto-tracing clipping plans with the view of endoscope
Coronal and sagittal clipping planes are activated. The view of endoscope is super-imposed in upper-left corner of each image.

3. Experiment

To evaluate the effect of navigation on improvement of endoscopic operation, an experiment was conducted. The following is its brief description.

Equipment

Fig. 5 shows the equipment used in the experiment. The subject is recorded by the camera behind the two monitors with time counter superimposed. The view of the endoscope is also superimposed to it for future analysis.

The right side ostium of maxillary sinus (Fig. 1) of the dummy skull was marked with colored ink prior to the experiment as the target. The target was shown on the navigation monitor as a small red cube, which was not affected by clipping planes.

Task

A subject is instructed to reach the target inside of the dummy skull with an endoscope and catch it into the endoscope view. During the task, subjects are required to be careful to avoid hitting the inside walls of the dummy skull with the tip of the endoscope. They are also instructed that it is better if they can finish the task faster, but time is not the primary concern of the experiment.

Endoscope Conditions

(A) Straight viewing (zero degree).

(B) Forward oblique viewing of 30 degrees.

Navigation Conditions

(1) Without navigation; endoscope monitor only.

(2) With navigation; auto-tracing sagittal clipping plane is active.

(3) With navigation; auto-tracing coronal clipping plane is active.

Subjects

Five adult Japanese who had no expertise in anatomy of the paranasal sinuses, endoscope operation, nor the navigation system.

Data

The execution time of the task, trajectory data of the tip of the endoscope, and the number of "accidents", or how many times the tip hit the wall, were recorded.

The navigation system is expected to improve the quality of the tasks. The analysis of the results has not been finished yet, though, execution time does not seem to differ so much, which is against our expectation. The effect of learning seems to be larger than the effect of navigation. The results of the experiment will be published in the near future.

4. Discussion and Future Work

The navigation system is our first step, though, new ideas of viewing cone, virtual endoscope, and auto-tracing clipping planes work well. Of course, there are many points to be improved. The following problems and suggestions have been pointed out by the authors and the subjects of the experiment:

- Better coloring is needed. Especially, sections shown by different clipping planes should have different color.
- 3D display device, such as liquid crystal shutter glasses, should be introduced.
- The light of the virtual endoscope should be improved to show the occlusion information correctly.

- Quicker response is needed.

An additional experiment should be conducted to compare the system and triplanar display. Clinical application also requires solutions of other problems such as registration.

5. Conclusion

A navigation system for endoscopic sinus surgery using VR technology was presented. The system simulates the real endoscope during surgery in real time; it shows the viewing field of the real endoscope as a viewing cone of the virtual endoscope. Clipping planes show the inside of the patient's head in 3D image. With auto-tracing clipping planes that follow the tip of the endoscope, 3D structure of the patient's head can be understood better. Techniques developed here, such as viewing cone and auto-tracing clipping planes, are applicable to other endoscopic surgeries as well. The system now enables "instrument flying" to some extent. Clinical application and training are its future goals.

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