Surgery Support System as a Surgeon's Advanced Hand and Eye

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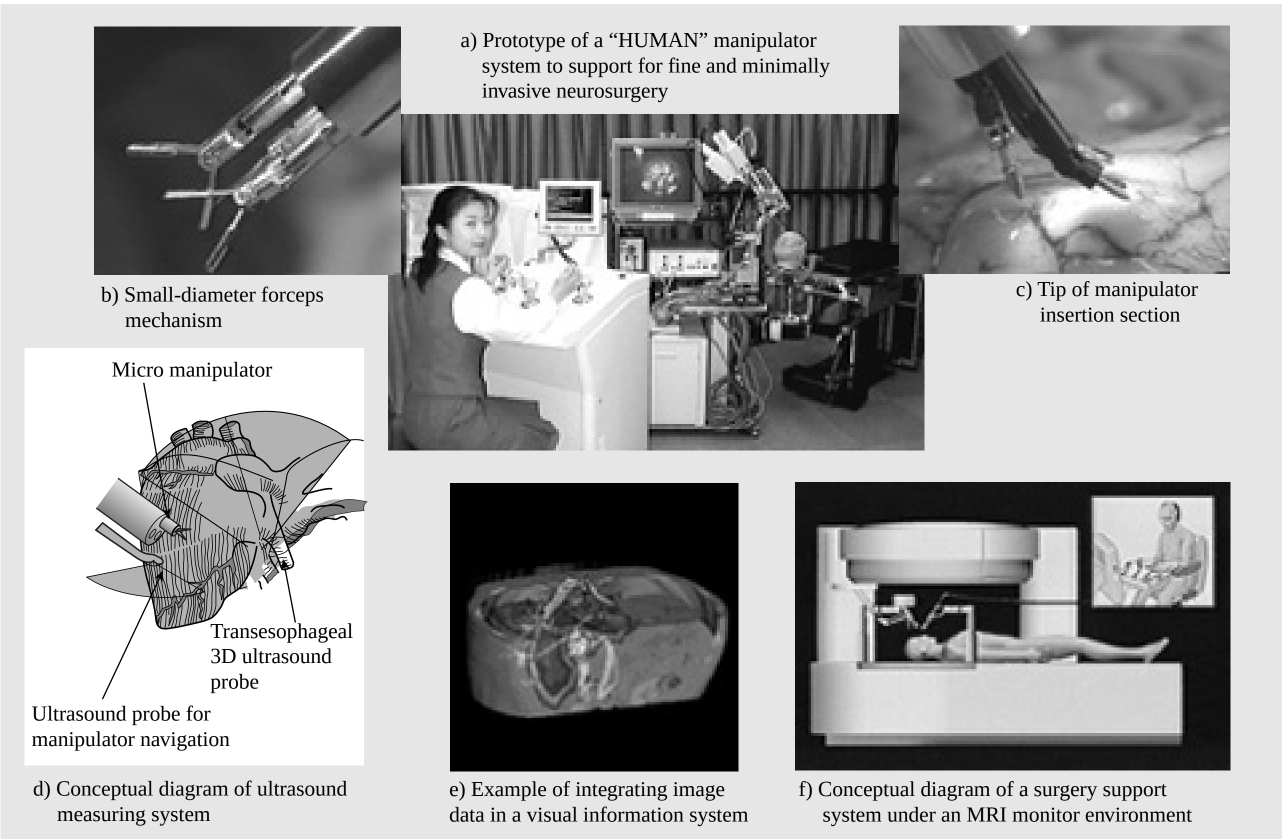
OVERVIEW: A "surgery support system" provides assistance with a new and advanced form of hand and eye. This system can achieve high-reliability surgery while being minimally invasive (small incisions) to minimize the burden on the patient. It is also expected to shorten treatment time and, on the whole, raise the patient's quality of life (QOL). In addition to developing manipulator systems for neurosurgery, Hitachi, Ltd. is researching and developing unified surgery support systems for minimally invasive treatment featuring advanced technologies like ultrasound measuring and image-data support.

INTRODUCTION

AT present, measuring technologies like X-ray computer tomography (CT) and magnetic resonance imaging (MRI) that can provide high-precision images of an affected part from outside the body are becoming indispensable to physicians in diagnosis work. In treatment, moreover, there is a need for a "new hand and eye" that can achieve highly reliable surgery while being minimally invasive (small incisions). Minimally invasive surgery is expected to raise the patient's quality of life (QOL) by easing the burden at the time of surgery and shortening treatment time. In this report,



a) Prototype of a "HUMAN" manipulator system to support for fine and minimally invasive neurosurgery
b) Small-diameter forceps mechanism
c) Tip of manipulator insertion section
d) Conceptual diagram of ultrasound measuring system
e) Example of integrating image data in a visual information system
f) Conceptual diagram of a surgery support system under an MRI monitor environment

MRI: magnetic resonance imaging HUMAN: hyper utility mechatronic assistant

Fig. 1— Surgery Support System as a Surgeon's New Hand and Eye.
Expansion toward a surgery support system under an MRI monitor environment unifying manipulator, measuring, and visual information systems.

we describe the present state and future outlook for surgery support systems that provide a surgeon with a new hand and eye to work with.

SURGERY SUPPORT MANIPULATOR SYSTEM

To support minimally invasive surgery in the field of neurosurgery, Hitachi, Ltd. has been developing manipulator systems especially for this type of surgery. The concept behind these systems is called Hyper Utility Mechatronic Assistant (HUMAN) Manipulator System,[1,2] which means a system that provides assistance through high-performance mechatronics technologies. In such a system, an insertion section is inserted through a small hole of about 10 mm in diameter in the patient's head, and HUMAN manipulators at the tip of that component supports the surgeon's hand while an endoscope lens supports the surgeon's eye. This system enables detailed minimally invasive surgery to be performed. To perform either surgery or treatment, the surgeon manipulates the insertion section through operation-input equipment while watching an endoscope monitor. A view of a prototype system is shown in Fig. 2. This system consists of (1) an operating console, (2) hold device, (3) a micro manipulator system, and (4) endoscope equipment.

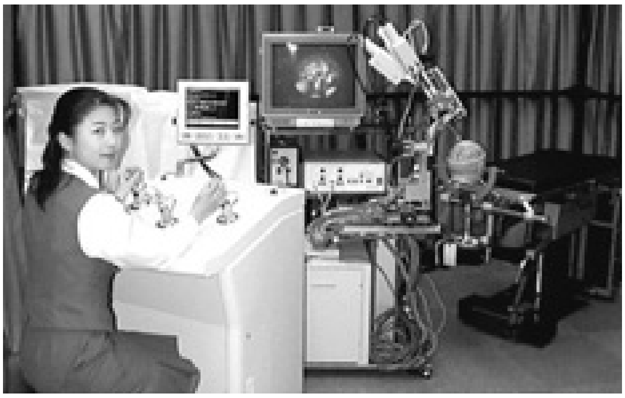


Fig. 2— Prototype of a HUMAN Manipulator System for Neurosurgery.
In the foreground to the left is the operating console; on the right, micro manipulators at the tip of a slender tube approaches the model of a human head from the upper left.

Fig. 3— Close-up of Insertion Section Tip.
A magnified view of the tip of the HUMAN manipulator insertion section is shown; micro forceps are attached to the tips of three micro manipulators.

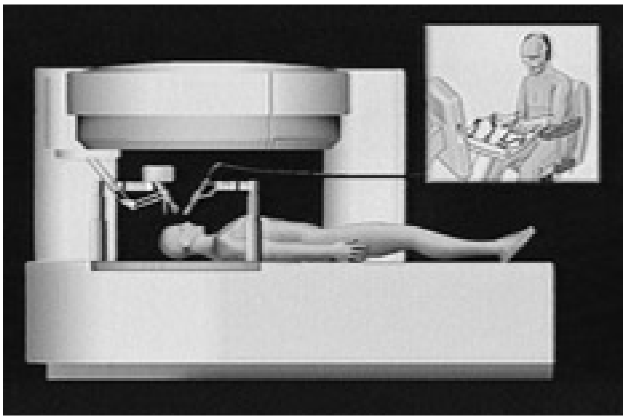


Fig. 4— Concept of a Surgery Support System Under an MRI Monitor Environment.
This illustration shows the image of a support system for diagnosis and treatment using a manipulator under an open-type MRI.

The tip of the insertion section in this system is shown in Fig. 3. It is equipped with three micro manipulators each having an outer diameter of 3 mm, with the hollow section of each manipulator accepting some sort of instrument. In this regard, the use of micro forceps[3] and optical fiber for surgical laser has already been shown to be feasible, and we are now at the stage of examining medical cases applicable to the system in cooperation with university hospitals.

In addition, research continues on combining this new-hand-and-eye manipulator technology with an MRI monitor environment with the goal of achieving a working system in the early part of the 21st century (see Fig. 4). Research also proceeds on ultrasound-measuring and image-data-support technologies under such an environment to develop unified surgery support systems featuring a surgeon's new hand and eye. These technologies are described below.

ULTRASOUND MEASURING TECHNOLOGY UNDER AN MRI ENVIRONMENT

Minimally invasive treatment and imaging support are inseparable. Take, for example, surgery associated with the circulatory system. Here, deformation of the

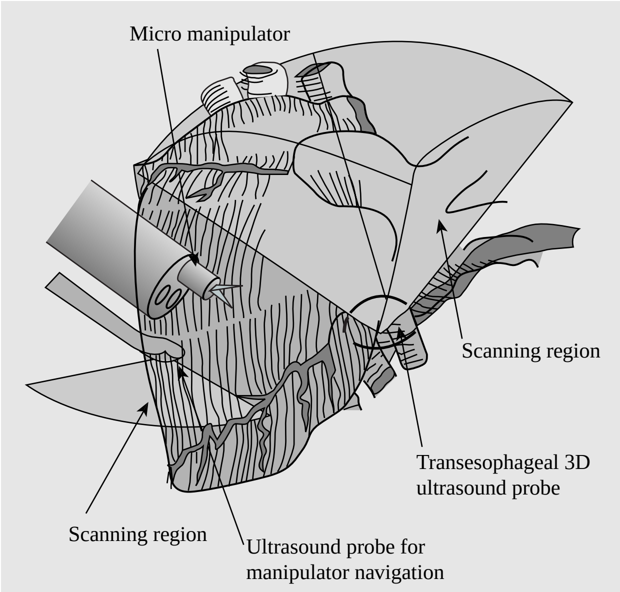


Fig. 5— Ultrasound Measuring During Surgery.
This diagram illustrates the capturing of the surgical field under an MRI monitor by multiple ultrasound probes.

targeted organ may change dramatically over time depending on the surgical method, and there is therefore a need for images that present the overall structure including the organ and its surroundings in addition to images like those obtained by an endoscope that give only local coverage.

With the development of open type MRI equipment that allows a surgeon access inside the gantry, interventional (concurrent with surgery) MRI has been thought to be important both in Japan and abroad. Magnetic resonance imaging, moreover, is applicable to computed tomography that provides support images of the type described above. Therefore, by constructing a system for treatment under an MRI monitor, it will be possible to provide images that show total structure in the area targeted for treatment so as to give the surgeon a "new eye."

In relation to the above, the operability of ultrasound measuring systems has been improving in recent years. This, in conjunction with high-speed, high-precision, and high-performance characteristics, enables such systems to supplement not only optical endoscopes as manipulator eyes but also real-time MRI data associated with local images of the surgery. With this in mind, efforts are being made to develop ultrasound probes using materials that do not disturb magnetic fields, and also, with the aim of decreasing the effects of radio frequency (RF) noise between measuring equipment, integrated sequence systems between measuring equipment to achieve efficient time sharing. Furthermore, the simultaneous use of multiple ultrasound probes like those for taking transesophageal three-dimensional images and high-speed, microminiature two-dimensional images, and the combination of bloodstream measurements by Doppler echoes and contrast echoes, can make a surgery support system even more convenient (see Fig. 5).

UNIFIED IMAGE PROCESSING SYSTEM

The usual process before surgery is to make a diagnosis and establish a plan of treatment based on the results of various examinations and images taken of the affected area. Such images will include data that depends on the features of the measuring and imaging equipment in question. It should therefore be possible to provide unified support for diagnosis and treatment by utilizing the respective features of image data from the various types of imaging equipment in an integrated manner.

Hitachi, Ltd. has been developing various technologies to enable image data to be used in diagnosis and treatment support. These include volume-rendering technology for interactive three-dimensional display[4)], technology for extracting focal points or key organs[5)], and technology for aligning images obtained from multiple imaging equipment.

These technologies will make it possible to prepare images that integrate form and function information (see Fig. 6). As shown, such an image makes it easy to

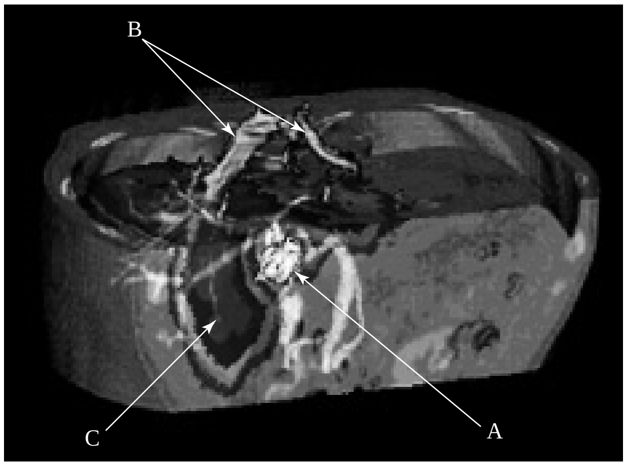


Fig. 6 — Example of Unifying Liver Image Information.
Data on a liver tumor (A) and surrounding blood vessels (B) are extracted from shape data obtained by X-ray CT and presented in 3D. Also, by synthesizing this with function data obtained by using radioactive isotopes, the activity ratio distribution of the liver function can be displayed. As a result, the 3D relationship between the liver function and the tumor can be visualized and used for surgical planning.

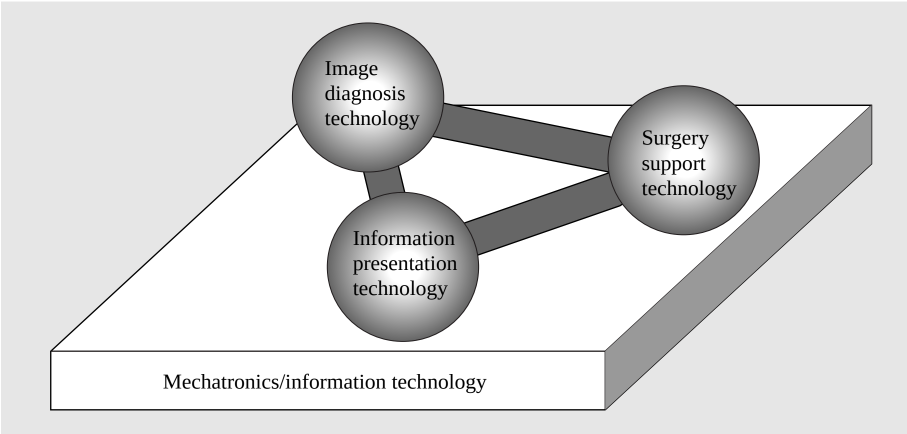


Fig. 7— The Various Technologies Making up Minimally Invasive Surgery and Treatment.
A variety of products for minimally invasive surgery and treatment will be formed by linking various technologies on a foundation of mechatronics and information technologies.

observe not only the affected part as obtained by X-ray CT (section A in the figure) and the three-dimensional relationship with neighboring blood vessels (section B), but also the current state of the liver function (section C). This makes it possible to decide on an appropriate surgical method and to establish a plan of treatment taking the patient's QOL after surgery into account.

Also, in the case of minimally invasive surgery under an endoscope, it becomes possible to integrate global information obtained by MRI with local images obtained by the endoscope. Providing support for such visual and positional information makes it easy for a surgeon to acquire sufficient spatial awareness.

For the future, our plan is to construct a unified image processing system that, in addition to enabling pre-surgery images to be referenced during surgery, will support the use of image data that integrates global information, function information, etc. This will be accomplished by taking images during surgery by ultrasound or MRI in addition to local endoscope images.

CONCLUSIONS

We have described a surgery support system that can play the role of a surgeon's new hand and eye. With support equipment for minimally invasive surgery already beginning to appear in Europe and North America, we are working to become a world leader in the provision of medical systems. To this end, with mechatronics technology and information technology as a foundation, we are developing surgery support technology based on manipulator systems to provide the surgeon's new hand, information presentation technology to assist in planning before and during surgery and to provide the surgeon's new eye, and image diagnosis technology to support imaging during surgery (see Fig. 7). Consideration is also being given to proposing "solutions" for the support of various types of minimally invasive surgery. These would consist of systems that support individual surgical processes by individual technologies and systems that provide total support for the surgery process flow by integrating these technologies. Hitachi, Ltd. aims to make a significant contribution to 21st century medicine by realizing a support system for minimally invasive surgery that is beneficial to both the patient and surgeon.

The authors would like to mention here that a neurosurgery manipulator system is being developed as the support system for brain tumors and other surgical operations, and that a surgery support system under an MRI monitor environment is being developed as the unified support system for diagnosis and treatment of heart disease, both under consignment from the New Energy and Industrial Technology Development Organization (NEDO) as a part of the Medical Welfare Equipment Technology Research and Development Policy.

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