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Newly Developing Endoscopic Devices — Shadow Optics and Micromachine —

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Abstract

Based on the newly-developed engineering technologies, many kinds of useful equipment have been available for minimally invasive surgery. Recently the time to connect clinical needs and advanced technologies has become faster. In this article, we have summarized the recent technologies for endoscopic surgeries. Shadow optic technologies for better geometric perception using dual illumination in a conventional 2-D monitor and "Overview optics" for a panoramic view with an additional visual system are introduced. Micromachine technology is very close to practical implementation for minimally invasive surgeries. Virtual Biopsy is the one of the hottest topics for the next generation of endoscopy. Stereoscopic and volumetric vision systems are still on the way, which should overcome the irritating goggles and stereo display devices. As well as operational theater that integrates all the required equipment with a computer-based system, including voice recognition, still requires the standard protocols to connect many kinds of devices from different manufacturers.

Key Words: Shadow telescope, overview optics, micromachine, minimally invasive surgery, virtual biopsy

INTRODUCTION

Connecting the telescopes with a CCD camera and monitor was a distinct advance in the history of endoscopic surgeries. There are always new technologies and clinical needs for easier and safer operations. Since the 1980s, many products have been developed based on electronic and computer technologies. When we compare the speed of introducing new technology with other industries, like communication or home appliances, medical equipment, especially surgical equipment, is the one of the last areas where new technology is applied as a serious product. One of the reasons is that medical products must guarantee safe operation and the another reason is the distance between end users and developers.

In this article, several newly-developed or developing technologies for minimally invasive surgeries are introduced. Most of them are based on optics and electronics.

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SHADOW OPTICS - A AELESCOPE WITH OPTIMIZED ILLUMINATION

The shadow telescope is a rigid 10 mm - endoscope with 30-degree view direction and uses additional illumination fibers ending at an optimized distance behind the front lens. This arrangement creates a more natural and more plastic appearance, a better-balanced contrast and a well-dosed visible shadow (Fig. 1a). The shadow gives additional secondary space clues and therefore improves orientation and judgement of the three-dimensional properties.

The soft shadows give a more natural and plastic impression of the operation field and improve the handling of surgical instruments. Especially the control of instruments that grasp tissue or suture organ surfaces (bowl, stomach) have been improved. When interacting with tissue, the shadow serves as a "touch control". The moment the instrument tip touches an organ surface, it also touches its own shadow.

Due to the increased distance between additional illumination and the operative field, the margins of the view field are particularly illuminated more homogeneously (Fig. 1b). At the same time the

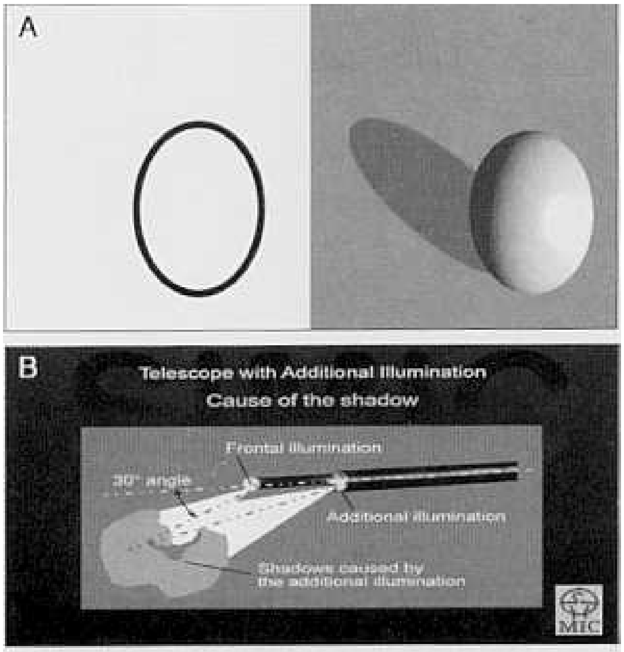

Fig. 1. (a) Shadow effect. (b) Structure of shadow telescope.

Fig. 2. Clinical image of shadow telescope: Behind the L-hook electrode, the shadow of it forms. It helps to get the idea of depth perception in space, even without 3-D camera or monitor.

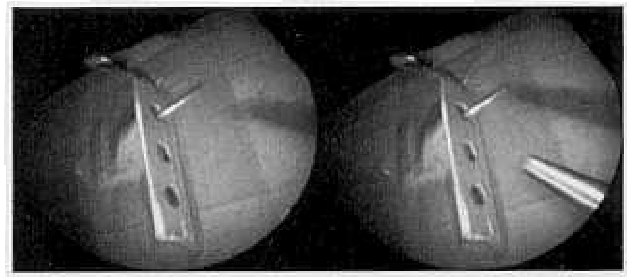

Fig. 3. Comparison task. without shadow (left) and with shadow (right). Operator can get an idea where his instrument is located with conventional 2-D monitor.

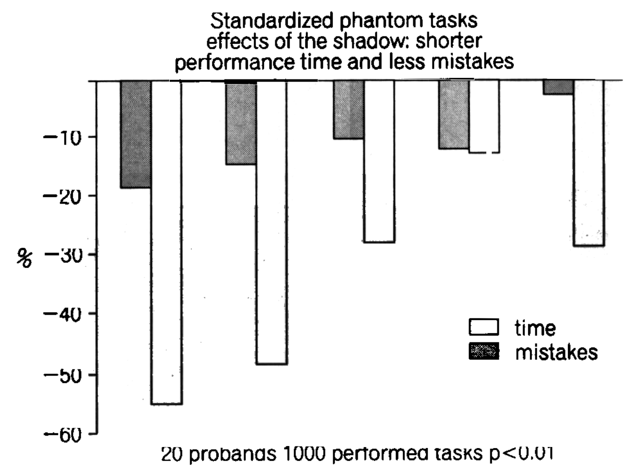

Fig. 4. Comparison result with the shadow, trainee can reduce the errors and time for a specific task.

blooming of the foreground which is common in close-up situations is reduced.

In addition, the optimized illumination supports the approach of instruments to the operative field. Laying behind the front lens, the additional fibers can generate shadows, when the tip of the instrument is still behind the front lens but already in front of the additional fibers.

The tip of the endoscope usually generates a little shadow usually at the upper edge of the endoscopic image. This shadow serves as an orientation mark of the view direction of the angulated shadow telescope. It is also a control that the additional illumination is working and that it is not dirty or restricted by the trocar. Fig. 2 shows the clinical image using shadow telescope during laparoscopy surgery, where the shadow of the instrument can be seen behind the upper of hook electrode.

A comparative study has been carried out at the university clinic of Tuebingen to raise objective data about the influence of the optimized illumination on surgical task efficiency. To guarantee reproducible conditions, the shadow telescope has been tested in a phantom setup with standardized surgical tasks. Five tasks imitated working steps of endoscopic surgery, like positioning, grasping, and stitching and they were sorted by their degree of difficulty. The execution of tasks was timed and the number of mistakes were electronically counted. Tasks 1 and 2 examined the orientation of the surgical instruments and the controlled approach to defined landmarks. Task 3 tests controlled grasping and dropping of objects of different sizes. Tasks 4 and 5 handled endoscopic suturing (Fig. 3). Twenty test subjects without endoscopic experience executed each of the 5 tasks 10 times, alternating with the shadow and without the shadow in randomized order. The data of 1000 performed tasks were statistically evaluated with chi-square-test. Each of the tasks was executed on average with 11% less time ($p<.01$) and with 33% fewer mistakes ($p<.01$) when using the shadow (Fig. 4).

MICROMACHINE APPLICATION

The concept of micromachine technology can be explained easily by inch worm motion. Using the LIGA (Lithography Galvanoformung Abformung) technology, micro fabrication of small parts can be produced in the order of microns. It means very small devices that can travel inside the human body for medicine can be made for a special purpose. This trend absolutely matches with minimally invasive surgery. The typical applications are micro activating ultrasound catheter for vascular diagnosis and micro surgery instruments. "A micro active bending ultrasound catheter using shape memory alloy" is one of the applications in this field. A micro injection (Fig. 5) pump can carry a small dose to a specified location in the patient. The prospect of an endoscope and instrument using micro machine technology[1,2] can be described as an integrated solution for vision and therapeutic instrument.

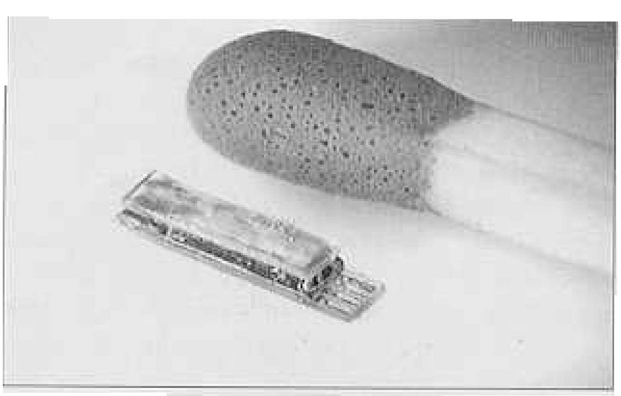

Fig. 5. Micro injection pump

Fig. 6. shows the schematic diagram of an ultrasound catheter using micrometer. Using a single chip transducer, it can increase the angular resolution without angular distortion.

OVER-VIEW OPTICS

During surgery for a beginner, hand-eye coordination is the most important point. Sometimes they lose the orientation and location inside the abdominal space. The concept of overview optics uses two fish-eye lenses and two 1/6" CCD cameras in addition to conventional laparoscopes. The participants in the operation can see with an additional monitor the overall view inside the abdominal space (Fig. 7). The subsidiary monitor displays a merged image with two cameras and the main monitor displays in front of the telescope. Optimal calculation of the visible area around trocar sleeve and illumination are the main concerns in this project.

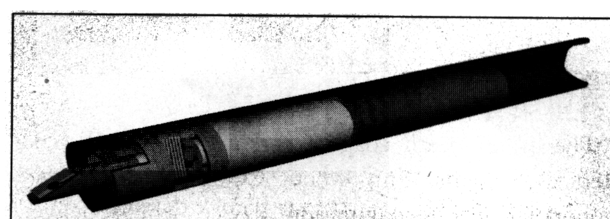

Fig. 6. Schematic diagram of intravascular ultrasound transducer for imaging of cross-section.

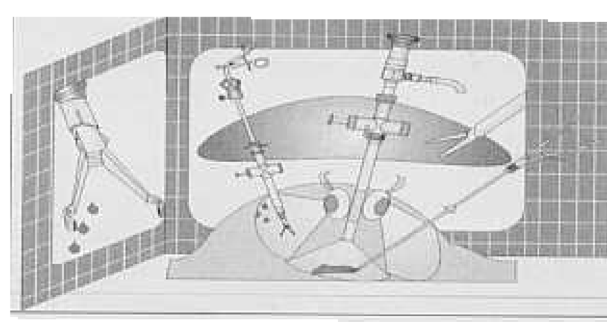

Fig. 7. The concept of overview optics. Doctors can see what is happening outside of the viewing telescope.

VIRTUAL BIOPSY WITH MULTI SPECTRUM IMAGE FUSION

General endoscopic image is the surface reflectance of the visible ray with high resolution and color reproduction on the monitor. Nowadays, many research groups around the world are interested in imaging with an infrared spectroscope. The IR wave penetrates 100 − 200 um from the surface and reveals information on metabolism. This new imaging technology can differentiate between cancerous tissue from healthy cells, even if there is no difference in general optical imaging. These difference can be found in the wave number of 1245 − 1195 cm^{-1} and 1045 − 995 cm^{-1}.

Another trial for diagnosis and therapy is fluorescence imaging and photodynamic therapy. Biochemical measurements of NADH (Nicotinamid Adenin Dinucleotid) or PP IX (Polyprophyrin IX) with special UV illumination can make a difference in the region of maligmoma such as squamous cell carcinoma or basalioma. Additionally, with these kinds of dye, Laser illumination can control for therapy of early cancer cells.

By overlapping these kinds of multispectral image with a normal optical image, biopsy can be done just with multi spectrum optics.

STEREOSCOPIC VISUALIZATION FOR ENDOSCOPY

Already several companies have announced stereoscopic endoscope systems using their own methods. A dual lens system with dual camera or a single lens system with dual camera, or a single camera with signal processed synthesized stereo image are the main examples. Volumetric image can serve better perception of the operation field, and this means safer and faster surgery. The main difference of these systems from 3-D MRI images is a stereoscopic, color, moving image versus still, black&white, volume-rendering image. These differences create difficulties for new products.

The stereoscopic image quality itself is far behind than the conventional 2-D image. Eye fatigue and irritating goggles are still controversial. The high price of a stereoscopic display device is one of the drawbacks in this field. But the fast speed of 3-dimensional image technology will make this concept possible in the near future.

INTEGRATED OPERATION THEATER

During endoscopic surgery in the operation room, so many kinds of machines from many manufacturers are used. Many doctors and nurses have difficulty operating of these machines. One prominent solution has been proposed by operation room installers. One example could be "Integrated control of the whole operation room with voice recognition". the bed, illumination, as well as endoscopic equipment like the camera, light source, gas insufflator, and HF surgery machine can be operated by the voice of the main surgeon.[3] The accuracy rate of oral command recognition should be guaranteed. For this kind of integration, every manufacturer must make a communication port for the main control unit. In PACS (Picture Archiving and Communication System), DICOM is the standard for every imaging machine from many companies like X-Ray, MRI, and ultrasound. Like DICOM, it is the problem of standard protocols that every company should follow to ensure an integrated operation room theater.

CONCLUSIONS

Some of these newly developed technologies will be the standards of surgery in the future and the other technologies will fade away from idea to just imagination for any number of reasons. One reason is the way of thinking from the engineering point of view. Clinical usefulness and profitability should not be omitted for designing new products. But those will also be the basis for advances in the medical equipment industries.

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