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Development of Broad-View Camera Unit for Laparoscopic Surgery

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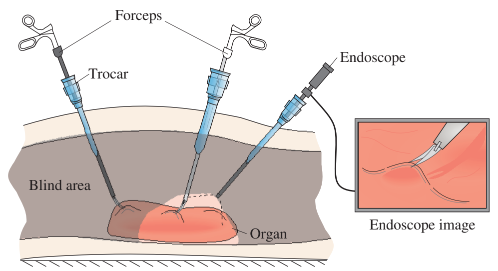
***Abstract*— A disadvantage of laparoscopic surgery is the narrow operative field provided by the endoscope camera. This paper describes a newly developed broad-view camera unit for use with the Broad-View Camera System, which is capable of providing a wider view of the internal organs during laparoscopic surgery. The developed camera unit is composed of a miniature color CMOS camera, an indwelling needle, and an extra-thin connector. The specific design of the camera unit and the method for positioning it are shown. The performance of the camera unit has been confirmed through basic and animal experiments.**

I. INTRODUCTION

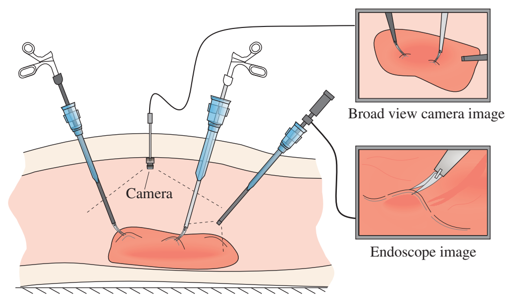
Laparoscopic surgery is a well-established method in modern medicine [1]–[4]. In laparoscopic surgery, a surgeon inserts several forceps and an endoscope into the abdomen through trocars, as shown in Fig. 1(a); therefore, large incisions, like the ones needed in open surgery, are not required. A surgeon performs this procedure while observing the target region as a two-dimensional visual image on a monitor. This is a minimally invasive procedure known for its important advantage of allowing quick recovery.

However, the limited field of view provided by an endoscope gives rise to the blind, as shown in Fig. 1(a). The disadvantage of a laparoscopic surgery is the narrow operative field provided by a single endoscope. Owing to this problem, the operating surgeon may overlook an adverse complication such as a bleeding. In fact, medical accidents have happened during surgical procedures.

A couple of studies have attempted to address this issue [5]–[7]. Since the early days of laparoscopic surgery, the double endoscope method had been proposed in clinical practice [6]. In this method, an additional endoscope is inserted in order to increase the view of the operating field. However, the insertion of an extra endoscope requires an additional incision for the insertion of trocar; this induces pain. Therefore, from the viewpoint of invasiveness, this approach is not used. On the other hand, Ohdaira et al. [7] have proposed the use of a wireless camera system for a minimally invasive surgery, especially NOTES (natural orifice translumenal endoscopic surgery) [8]–[10]. The miniature camera is inserted into the patient's body via a trocar, and it transmits images of a wide operative field using an RF signal. However, the size of the camera is of the order of a few centimeters (this includes the battery, power circuit, transmitter circuit, and camera-fixing mechanism). Therefore, it cannot be inserted into the body through a trocar.



(a) Setup of laparoscopic surgery



(b) Proposed system

Fig. 1. Basic concept of Broad View Camera System

Considering this background, we have proposed a Broad-View Camera System, with the aim of providing a wider view of the operating field by using a miniature wired camera unit that can be placed within a patient's body, as shown in Fig. 1(b) [11]. With the use of this system, the invasiveness of the procedure is not increased and the specification of current laparoscopic surgery is maintained. Furthermore, it can function as a second camera (in addition to the one attached to the endoscope) and can help assess the overall state of the target area. In this paper, we discuss this newly developed broad-view camera unit, which is intended for use along with the Broad-View Camera System. The remainder of this paper is organized as follows. In section II, we show the basic design and the procedure for positioning the developed broad-view camera unit. In section III, we describe the basic experiments that are essential to confirm

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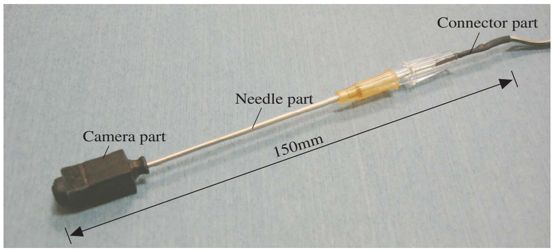
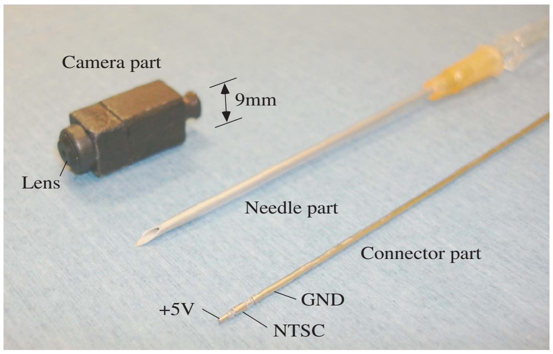
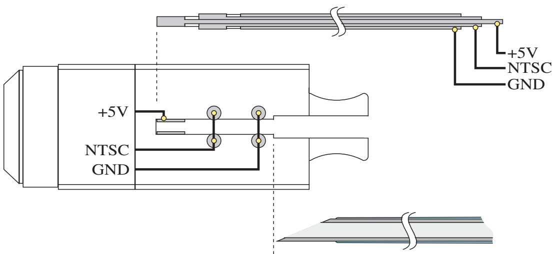


(a) An overview of the developed camera unit

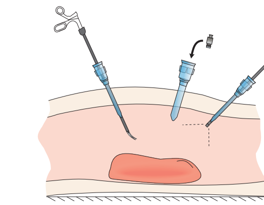


(b) Three parts of the camera unit

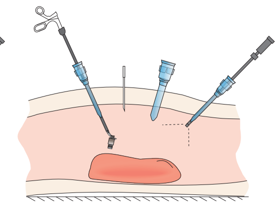


(c) The configurations of the camera unit

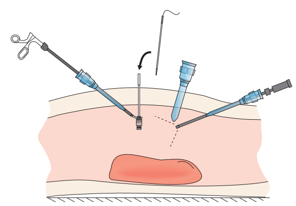
Fig. 2. The design of the broad view camera unit



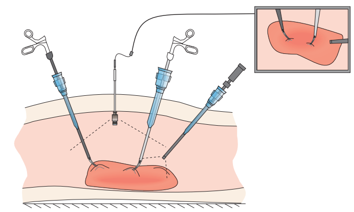
(a) Step 1



(b) Step 2



(c) Step 3



(d) Step 4

Fig. 3. Locating sequence of the camera unit

the performance of the camera unit, and we describe the in vivo experiments performed using the pig lung. Finally, in section IV, we discuss the concluding remarks of the present study and our future plans.

II. THE BROAD-VIEW CAMERA UNIT

A. Design

Fig. 2(a) shows an overview of the broad view camera unit. The camera unit is composed of 3 mechanical parts – camera, needle, and connector.

Camera part: This part consists of (i) a color CMOS camera (9.0 $\times$ 9.0 $\times$ 10.0 mm; 510 $\times$ 492 pixels). It captures images of the operative field at 30 fps and (ii) a plastic base for connecting the CMOS camera, as shown in Fig. 2(b). The inside of the plastic base is wired such that it can be connected to the 3 lines of the CMOS camera (+5.0 V, GND, NTSC), as shown in Fig. 2(c). The plastic base is curved such that it can be handled with forceps.

Needle part: This part consists of an indwelling needle employed for medical use (inner diameter: ϕ1.1 mm, outer diameter: ϕ1.6 mm) for fixing the camera part within the patient's body. It is connected to the camera part by applying friction force between the plastic base and the outside of the needle, as shown in Fig. 2(c).

Connector part : It consists of (i) 3 Ni pipes (ϕ0.3 $\times$ 140.0 mm for +5 V power supply, ϕ0.5 $\times$ ϕ0.7 $\times$ 130.0 mm for NTSC signal, and ϕ0.9 $\times$ ϕ1.1 $\times$ 120.0 mm for the GND line) that are used for connecting the 3 lines of the CMOS camera to the outside of the body and (ii) 2 plastic tubes (radial thickness 0.1 mm) for isolating the Ni pipes, as shown in Fig. 2(b)(c).

B. Method for Positioning the Camera Unit

The camera unit is placed within the patient's body by following the 4 steps mentioned below (Fig. 3).

1. The camera part is inserted in the body through a 12-mm trocar (Fig. 3(a)).
2. By using an endoscopic image, the camera part is grasped with a forceps and the needle part is fixed to the abdomen externally (Fig. 3(b)).
3. The camera part is connected to the needle part by manipulating it with the forceps, and the connector part is inserted into the needle externally (Fig. 3(c)).
4. The connector part is fixed to the camera part, and the image captured by the CMOS camera is displayed on a monitor (Fig. 3(d)).

The broad-view camera unit is thus assembled as a wired monitoring camera device, as shown in Fig. 2(a). To remove the camera unit from the body, the abovementioned steps are performed in the reverse order. Fig. 4 shows an overview of a demonstration of the camera unit.

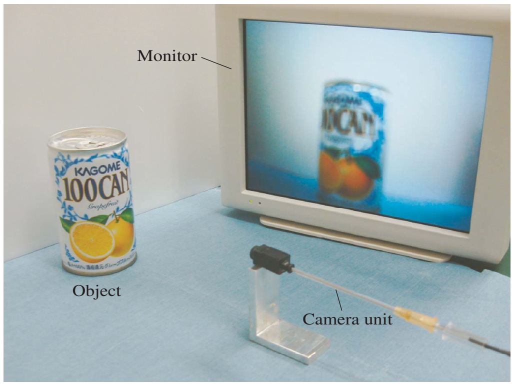
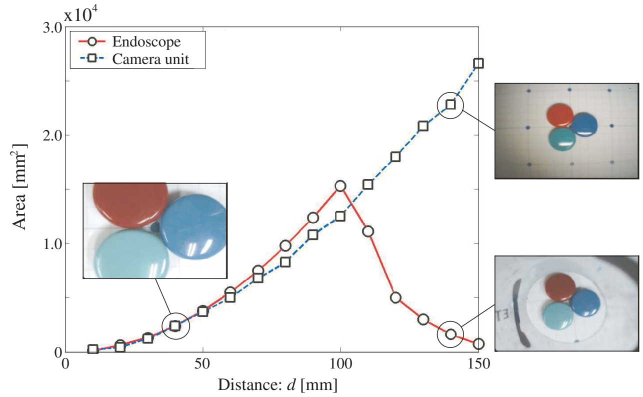
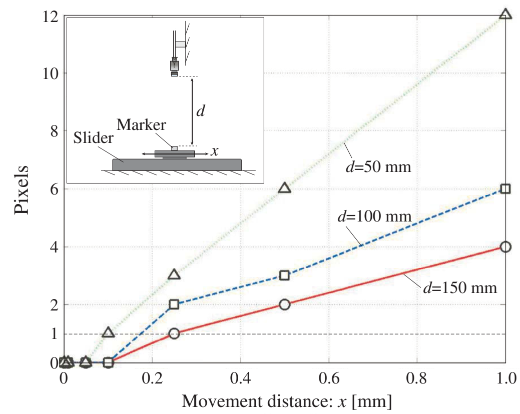


Fig. 4. Demonstration of the camera unit



(a) Comparison between an endoscope and the developed camera unit



(b) Spatial resolution

Fig. 5. Basic performance of the developed camera unit

III. EXPERIMENTS

A. Basic Experiments

Before animal experimentations, we performed 2 basic experiments to confirm the performance of the broad-view camera unit.

First, we compared the field of view between an endoscopic camera and our camera unit. Fig. 5(a) shows the area observed using each camera when moving it along a horizontal line, where d is the distance between the tip of the marker and that of each camera. In this experiment, the endoscope was inserted into a trocar, similar to the procedure followed in a laparoscopic surgery. From Fig. 5(a), we can see that for the endoscopic camera, the observed area increased when d = 100 mm; however, the observed area decreased when d was greater than 100 mm. On the other hand, the wide-field of view was maintained with the broad-view camera unit. In this experiment, we confirmed that at d = 150 mm, the observed area with our camera unit is approximately 8 times greater than that with an endoscopic camera.

Next, we determined the spatial resolution of the developed camera unit. Fig. 5(b) shows the pixels that moved when the camera unit was moved along the horizontal line and the marker was moved in the vertical direction by using a slider; d is the distance between the marker and the camera, x is the distance moved by the slider, and the diameter of the marker is 5 mm. In this experiment, the number of pixels that moved was calculated by measuring the center of gravity of the marker movement. From Fig. 5(b), we can see that the developed camera unit has a spatial resolution of at least 250 μm. Therefore, it can be used for examining the interior of the body, for example, the movement of surgical tools.

On the basis of these experiments, we concluded that the performance of the developed camera unit was enough to obtain a wide field of view for a surgical procedure.

B. Animal Experiments

To simulate the conditions of actual laparoscopic surgery as accurately as possible, 5 trocar ports (4 for 5-mm trocars and 1 for 12-mm trocar) were placed in a pig's abdomen. Fig. 6 shows an overview of the assembly of the camera unit that was carried out using a forceps and an endoscope. Fig. 7(a) and (b) show the images obtained using the endoscope and broad-view camera unit, respectively. Throughout the operation, the endoscope, forceps, foreign material, and colon of the pig were continuously monitored using the camera unit, as shown in Fig. 7(b). On the basis of this result, we think that the camera unit has enough spatial resolution to demonstrate the conditions inside the body. However, in future studies are required to improve the performance of the CMOS camera for better clarity of observation.

During this experiment, the lens of the camera did not mist over because of the surgical conditions, such as an incision with a radio knife. Furthermore, when the camera lens was dirty, we could clean the lens using a water-jet and gauze.

We confirmed the utility of the developed camera unit in the animal experiments. We think that the proposed camera system has momentous potential for use as a visual-navigation system during laparoscopic surgery.

IV. FUTURE WORKS AND CONCLUSIONS

A. Future Works

From the results of the animal experiment, it was confirmed that the new camera unit cannot be assembled easily. In the future, we plan to resolve this issue by redesigning

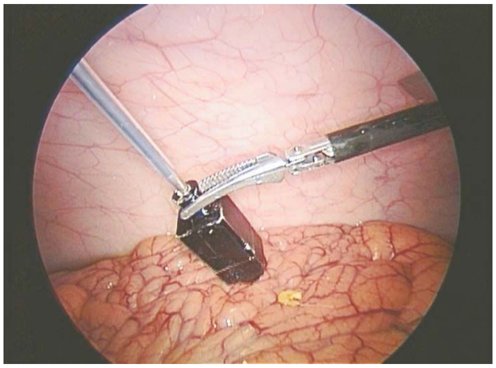
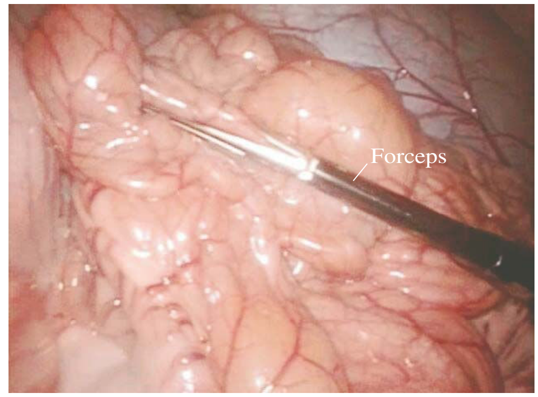
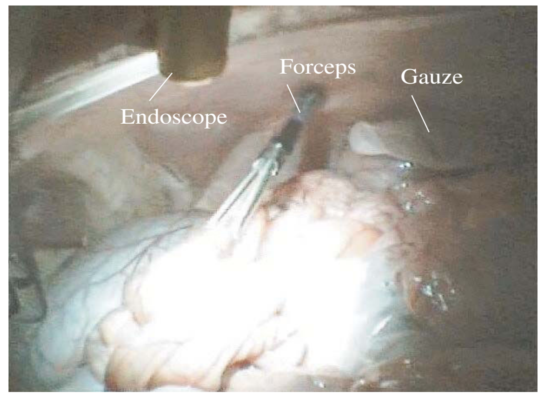


Fig. 6. An overview of the camera unit assembling



(a) Image of the endoscope



(b) Imege of the developed camera unit

Fig. 7. Overview of animal experiment

the plastic base of the camera part. We also aim to evaluate the effect of the position of the camera within the body and verify the effect of endoscope lights by conducting an animal experiment.

Furthermore, on the basis of the abovementioned experimental results, we are currently developing a monitoring system for surgical field analysis that can be conducted during laparoscopic surgery. With this system, multiple camera units can be used to measuring the movement of surgical tools.

B. Conclusions

Here, we described a newly developed broad-view camera unit that can be applied to laparoscopic surgery. The main results of our study are as follows:

(1) The broad-view camera unit is composed of a miniature color CMOS camera, an indwelling needle, and a 1.1-mm-wide connector. These mechanical elements are assembled within the patient's body.

(2) Through our basic experiments, we have confirmed the field of view and the spatial resolution characteristics of the camera unit.

(3) Throughout our in vivo animal experiments, we confirmed that the usability of the described camera unit is higher than that of a conventional endoscope.

V. ACKNOWLEDGMENTS

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REFERENCES

[1] H. Hasegawa, Y. Kabeshima, M. Watanabe, S. Yamamoto, and M. Kitajima: Randomized controlled trial of laparoscopic versus open colectomy for advanced colorectal cancer, *Surg Endosc*, vol. 17, no. 4, pp. 636–640, 2003.

[2] K. Moorthy, Y. Munz, S.K. Sarker, and A. Darzi: Objective assessment of technical skills in surgery , *BMJ*, vol. 327, no. 7422, pp. 1032–1037, 2003.

[3] Clinical Outcomes of Surgical Therapy Study Group: A comparison of laparoscopic assisted and open colectomy for colon cancer, *N Engl J Med*, vol. 350, no. 20, pp. 2050–2059,2004.

[4] R. Gonzalez, C.D. Smith, S.G. Mattar, K.R. Venlatesh, E. Mason, T. Duncan, R. Wilson, and J. Miller: Laparoscopic vs open resection for the treatment of diverticular disease, *Surg Endosc*, vol. 18, no. 2, pp. 276–280, 2004.

[5] K.M. Irion, P. Schwarz, and M. Kocher: Device for intracorporal minimalinvasive treatment of a patient, United States Patent, No.: US6648816 B2.

[6] R.B. MacAnally, C.D. Cawood: Dual view endoscope, United States Patent, No.: 4846154.

[7] T. Ohdaira, Y. Yasuda: Usefulness of visual field securement in NOTES by a wireless micro CCD camera that is insertable intraperitoneally through the gastrointestinal tract, *Proc. of the Society of American Gastrointestinal and Endoscopic Surgeons 2008 Annual Meeting*, ETP065, p. 321, 2008.

[8] C.W. Ko, A.N. Kallo: Per-oral transgastric abdominal surgery, *Chin J Dig Dis*, No. 7, pp. 67–70, 2006.

[9] M.S. Wagh, B.F. Merrifield, and C.C. Thompson: Survival studies after endoscopic transgastric oophorectomy and tubectomy in a porcine model, *Gastrointest Endosc*, No. 63, pp. 473–478, 2006.

[10] T.H. Baron: Natural orifice transluminal endoscopic surgery, *British Journal of Surgery*, No. 94, pp. 1–2, 2007.

[11] T. Kawahara, M. Okajima, I. Ishii, T. Takaki, D. Sumitani, and M. Yoshida: Broad-view camera system for endoscopic surgery, *Proc. of the Society of American Gastrointestinal and Endoscopic Surgeons 2009 Annual Meeting*, 2009.