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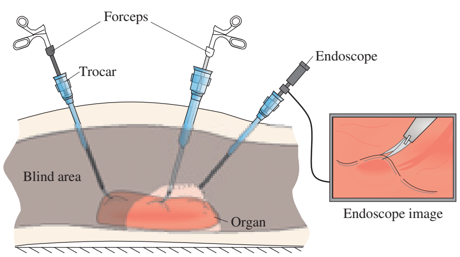
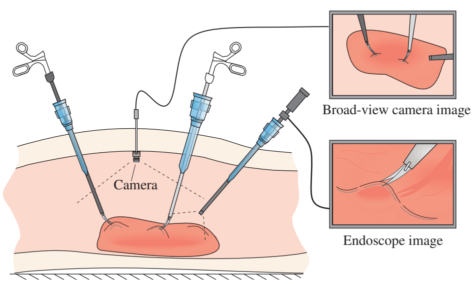
# Development of a Broad-View Camera System for Minimally Invasive Surgery

Tomohiro Kawahara, Takeshi Takaki, Idaku Ishii, and Masazumi Okajima

***Abstract*— A big advantage of minimally invasive surgery is the quick recovery afforded by the minimal physical injury sustained by patients. However, the operative field provided by the endoscope camera is rather narrow. This paper discusses a new broad-view camera system, which is capable of providing a wider view of the internal organs during minimally invasive surgery. This system consists of a camera unit for capturing the image and a monitor for displaying the captured image. With the use of this system, the invasiveness of the procedure does not increase, and the other specifications of current minimally invasive surgery are 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 present this a newly developed camera system, which is intended for use along with the proposed system. The camera system 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 here. The performance of this camera system has been confirmed through basic and laparoscopic surgery on animals.**




(a) Setup of minimally invasive surgery (e.g., laparoscopic surgery)




(b) Proposed system

Fig. 1. Basic concept of the broad-view camera system

## I. Introduction

Minimally invasive surgery is a well-established method in modern medicine [1]–[4]. In minimally invasive surgery, a surgeon inserts several forceps and an endoscope into the patient's body through trocars, as shown in Fig. 1(a); therefore, large incisions, like the ones used in open surgery, are not required. A surgeon performs this procedure while observing a two-dimensional visual image of the target on a monitor. This is a minimally invasive procedure known for the quick recovery it offers.

However, the limited field of view provided by the endoscope camera gives rise to a blind area, as shown in Fig. 1(a). The disadvantage of minimally invasive surgery is the narrow operative field provided by a single endoscope. Owing to this problem, the operating surgeon may overlook adverse complications such as bleeding. In fact, this has caused medical accidents during surgical procedures.

A couple of studies have attempted to address this issue [5]–[8]. Since the early days of minimally invasive surgery, the double-endoscope method has been proposed in clinical practice [6]. In this method, an additional endoscope is inserted in order to increase the range of view of the operating field. However, the insertion of an extra endoscope requires an additional incision for insertion of the trocar; this induces pain. Therefore, from the viewpoint of invasiveness, this approach is not used. On the other hand, Ohdaira et al. [8] have proposed the use of a wireless camera system for minimally invasive surgery, especially natural orifice translumenal endoscopic surgery (NOTES) [9]–[11]. The miniature camera is inserted into the patient's body via a trocar, and it transmits images of a wide operative field using a radio frequency 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.

Considering all this, we discuss 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). With the use of this system, the invasiveness of the procedure is not increased and the specifications of current minimally

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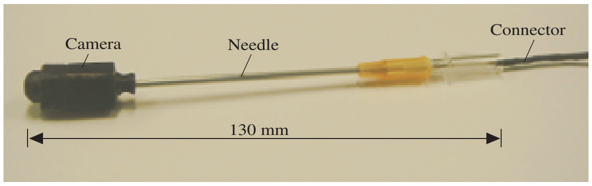



Fig. 2. An overview of the developed camera unit

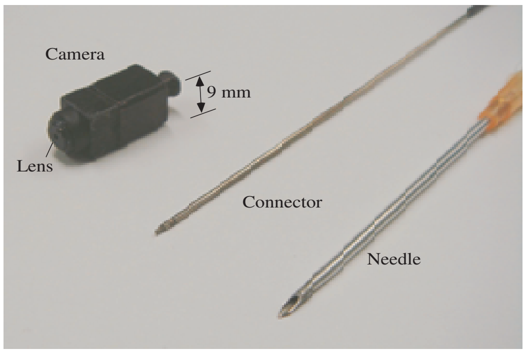



Fig. 3. The 3 parts of the camera unit

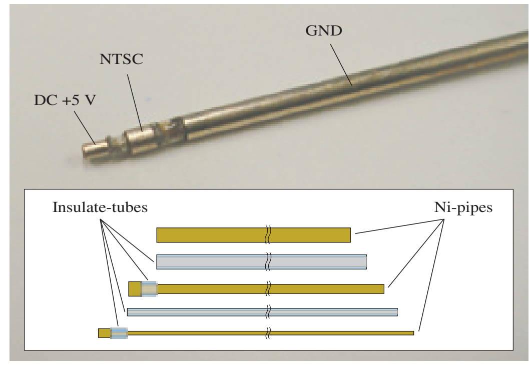



Fig. 4. Specifications of the connector

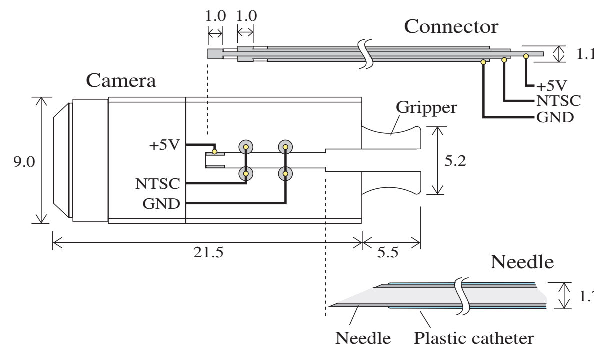



Fig. 5. Configurations of the camera unit

invasive surgery are 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 present the newly developed 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 camera unit. In section III, we describe the basic experiments that are essential to confirm the performance of the camera unit, and we describe the in vivo experiments performed on the pig. In section IV, we discuss the remaining issues that need to be addressed for clinical application and our future plans. Finally, in section V, we present the concluding remarks of the present study.

## II. THE BROAD-VIEW CAMERA SYSTEM

### A. Concept

The proposed system consists of a camera unit for capturing the images of the body and a monitor for displaying the captured image, as shown in Fig. 1(b). In this system, the camera unit is assembled by forceps inside the patient's body. By using this method, we can assemble the camera unit inside ; in this way, both the setup and invasiveness of minimally invasive surgery remain the same.

### B. Design

Fig. 2 is an overview of the developed camera unit. The camera unit is composed of 3 mechanical parts–camera, needle, and connector.

**Camera:** This part consists of (i) a 1/4-inch color CMOS imager (9.0 × 9.0 × 10.0 mm; 510 × 492 pixels), which captures images of the operative field at 30 fps; (ii) a plastic camera lens (f 3.1 mm, F 3.4, focusing range: 30–$\infty$ mm); and (iii) a camera base for connecting the CMOS imager, as shown in Fig. 3. The camera base is molded by epoxy resin and is covered by a water-repellent sheet for medical use. The inside of the camera is wired by Ni-pipes/wires such that it can be connected to the 3 lines of the CMOS camera (DC +5.0 V, GND, and NTSC), as shown in Fig. 5. The camera has a gripper, which is curved such that it can be handled with forceps. The length and weight of the entire camera are 27.0 mm and 3.0 g, respectively.

**Connector:** It consists of (i) 3 Ni-pipes ($\phi$ 0.3 × 140.0 mm for +5 V power supply, $\phi$ 0.5 × $\phi$ 0.7 × 130.0 mm for the NTSC signal, and $\phi$ 0.9 × $\phi$ 1.1 × 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, as shown in Fig. 3, and (ii) 4 PTFE tubes (radial thickness, 0.1 mm) for isolating the Ni-pipes, as shown in Fig. 4. For displaying the captured image on the monitor, the connector is connected to the camera as shown in Fig. 5.

**Needle:** This part consists of an indwelling needle employed for medical use (inner diameter: 1.1 mm, outer diameter: 1.6 mm), for fixing the camera in the body. It is connected to the camera by application of friction between the plastic base and the outside of the needle, as shown in Fig. 5. Since the plastic catheter (outer diameter: 1.7 mm) covers the needle as shown in Fig. 5, the needle does not contact the patient's

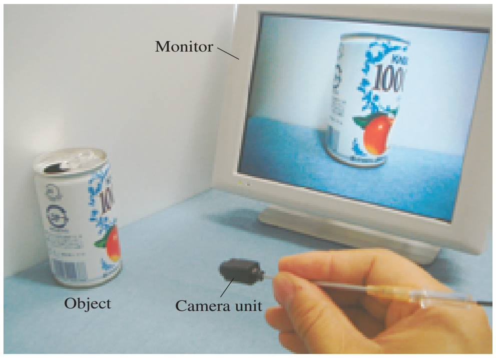
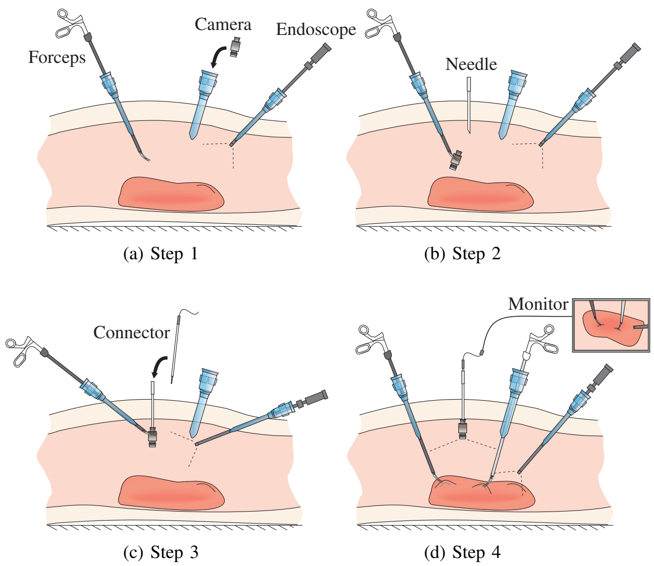


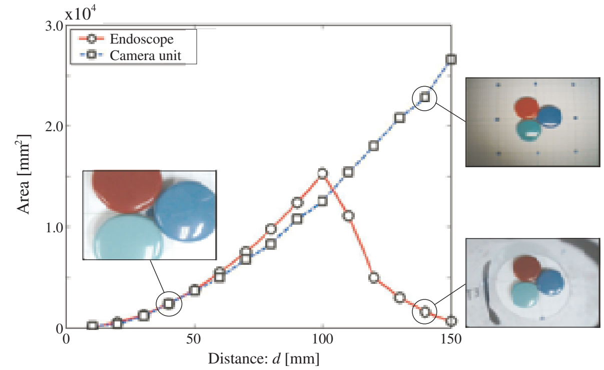

Fig. 6. Demonstration of the camera unit



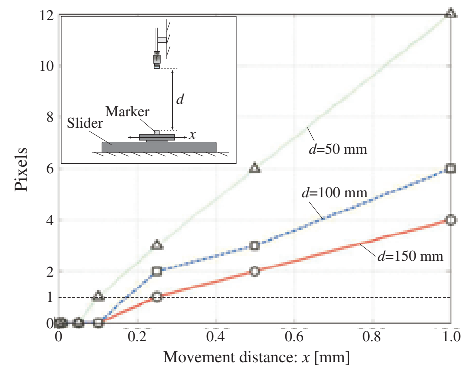

(a) Step 1 (b) Step 2

(c) Step 3 (d) Step 4

Fig. 7. Sequence for positioning of the camera unit




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




(b) Spatial resolution

Fig. 8. Basic performance of the developed camera unit

body when we insert the needle into the body.

Fig. 6 is an overview of the use of the developed camera unit. In the preliminary experiment, we confirmed that when we pull the connector with a force of over 2.5 N, the connector is detached from the camera. We also confirmed that when we pull the needle with a force of over 6.0 N, the needle is detached from the camera.

### C. Method for Positioning the Camera Unit

The camera unit is placed within the patient's body by the following 4 steps (Fig. 7).

1. The camera is inserted in the body via a 12-mm trocar (Fig. 7(a)).
2. With the guidance of an endoscopic image, the camera is grasped with a forceps, and the needle is fixed to the abdomen externally (Fig. 7(b)).
3. The camera is connected to the needle by manipulating it with the forceps, and the connector is inserted into the needle externally (Fig. 7(c)).
4. The connector is fixed to the camera, and the image captured by the CMOS camera is displayed on a monitor or a PC (Fig. 7(d)).

The camera unit is thus assembled as a wired monitoring camera device, as shown in Fig. 2. To remove the camera unit from the body, the abovementioned steps are performed in the reverse order.

Although with the proposed positioning approach, there is 1-mm invasion, the patient will have no scar after surgery.

## III. Experiments

### A. Basic Experiments

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

First, we compared the field of view between an endoscope and the camera unit. Fig. 8(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 minimally invasive surgery. From Fig. 8(a), we can see that for the endoscope, 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 newly developed camera unit. In this experiment, we confirmed that at $d$ = 150 mm, the observed

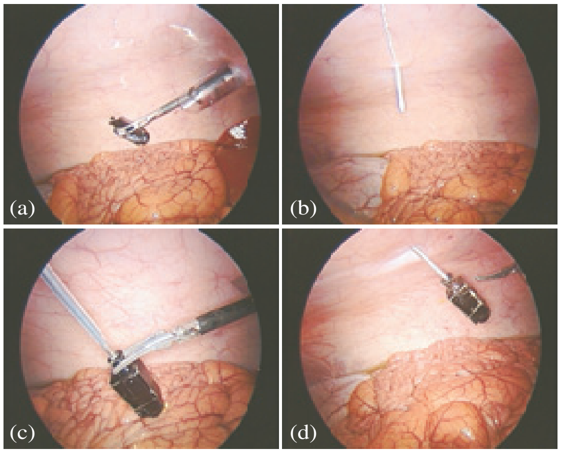



Fig. 9. Overview of the assembly of the camera unit

area with the newly developed camera unit is approximately 8 times greater than that with an endoscope.

Next, we determined the spatial resolution of the newly developed camera unit. Fig. 8(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 with 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. 8(b), we can see that the newly developed camera unit has a spatial resolution of at least 500 $\mu$m (Hi-vision laparoscope: less than 250 $\mu$m). Therefore, it can be used for examining the interior of the body, for example, movement of surgical tools.

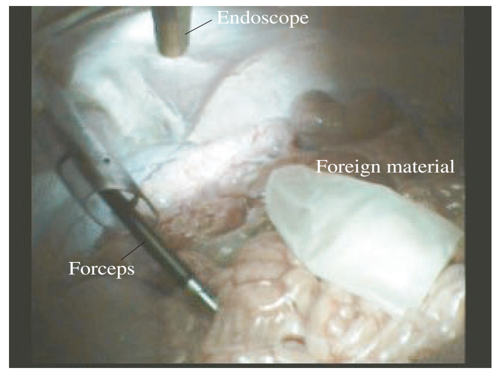
On the basis of these experiments, we concluded that with this newly developed camera unit, it was possible to obtain a wide field of view.

### B. Animal Experiments

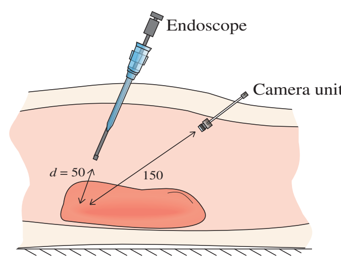
We performed laparoscopic surgery on 4 pigs. To simulate the conditions of actual laparoscopic surgery as accurately as possible, 5 trocar ports (four 5-mm trocars and one 12-mm trocar) were placed in the abdomen. Fig. 9 shows an overview of the assembly of the camera unit that was carried out using a forceps and an endoscope. After the assembling, the posture of the camera unit is fixed by a holder which is placed on the surface of the pig's abdomen. We found that an average of 180 s was required for positioning the camera unit, and an average of 90 s for removing it.

Fig. 10(a), (b), and (c) show the images obtained using the endoscope, the images obtained using the camera unit, the positional relationship of the endoscope camera and the 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. 10(b).

(a) Endoscope image




(b) Image obtained with the newly developed camera unit




(c) Experimental setup

Fig. 10. Overview of the animal experiment

Next, we applied the developed system to analyze the movement of forceps as an application example. In this experiment, the surgeon approached the liver 10 times by using forceps to which colored markers were attached. Fig. 11 shows the experimental results: the plot line shows the trajectory of the forceps obtained after image processing. From this result, we confirmed that the developed system can detect the movement of medical instruments in minimally invasive surgery. On the basis of this result, we think that the camera unit has enough spatial resolution to demonstrate the conditions inside the body. However, the performance of the CMOS camera needs to be improved to increase the clarity of the images.

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

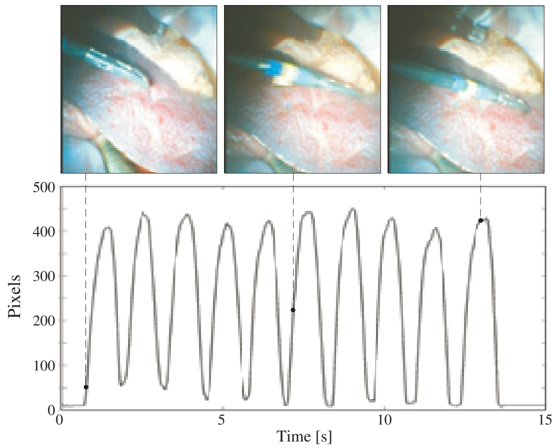
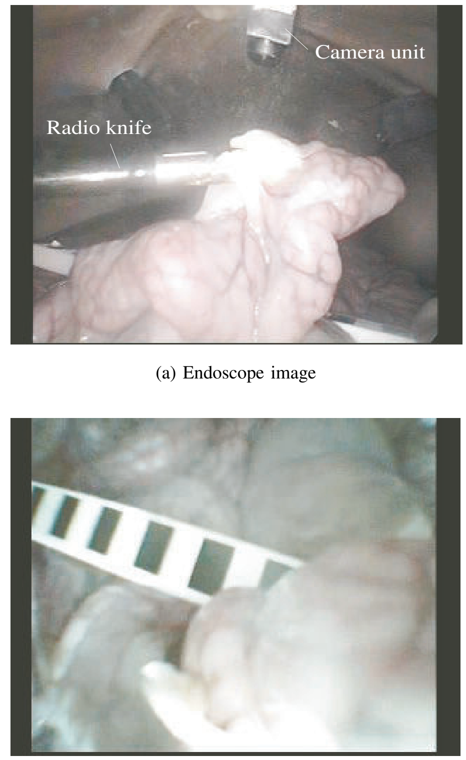



Fig. 11. An example of the detection of movement of the forceps determined from images obtained with the newly developed system




(a) Endoscope image

(b) Image captured with camera unit

Fig. 12. Effect of the fogging caused by incision with the radio knife

## IV. Discussions and Future Works

For clinical application of this newly developed system, the following issues need to be resolved.

**Fogging of the camera lens:** During the animal experiment, the lens of the camera did not mist over because of the surgical conditions, such as an incision with a radio knife, as shown in Fig. 12(a) and (b). Furthermore, when the camera lens was dirty, we could clean the lens with a water jet and gauze.

**Light source for the camera unit:** In the animal experiment, the brightness of the light source of the camera unit was not enough for monitoring the entire surgical field. Therefore, we think that the next version of this camera unit will require LED light source.

**Assembly of the camera unit:** From the results of the animal experiment, it was confirmed that assembly of the camera unit occasionally requires time. In the future, we plan to resolve this issue by redesigning the plastic base of the camera.

**Optimal position of the camera unit:** In the future, we also aim to determine the optimal position of the camera within the body and verify the effect of the endoscope light source by conducting an animal experiment.

**Effect of attached blood:** As a precautionary measure, we examined the image noise by blood which is attached to the connector of the camera unit. Fig. 13 shows the experimental resuts. From Fig. 13(b), we can see that the color of the image is changed by blood. If these image noises affect to the monitoring, we may change the camera unit. Since the camera unit can be produced at a low cost (roughly less than 100 $), it can be a disposable.

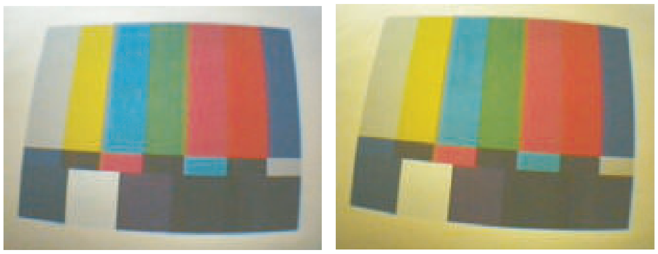
**Monitor for surgeon:** In current setting of the system, an additional display is needed for providing the captured image from the camera unit. To avoid a stress for surgeon, a superimposed display included both a laparoscopic and a broad-view image should be used.

**Other application:** On the basis of the abovementioned experimental results, we think that the proposed system is also useful for a mirror image problem in the laparoscopic surgery. By using the broad-view image, the assistant can observe the surgical field without a rotation of image. In addition, we are currently developing a real-time monitoring system for surgical field analysis that can be conducted during laparopic surgery. With this system, multiple camera units can be used to measure the movement of surgical tools. We believe that the proposed system can be applied to other minimally invasive surgeries (hybrid-NOTES [12], single-port endoscopic surgery [13], VATS [14][15], etc.). Furthermore, we plan to merge the camera unit with the other developed medical devices [16] and sensors [17], as shown in Fig. 14. We believe that the broad view provided by this camera system will increase the efficiency of medical devices and sensors.

## V. Conclusions

In this paper, we developed a broad-view camera system, which is composed of a camera unit and a display monitor, for application in minimally invasive surgery. The main aspects of our study are as follows:

1. The camera unit is composed of a miniature color CMOS camera (width, 9.0 mm), an indwelling needle, and a 1.1-mm-wide connector. These mechanical elements are assembled within the patient's body.



(a) Without blood　　(b) With blood

Fig. 13. Image noise by the attached blood to the connector part

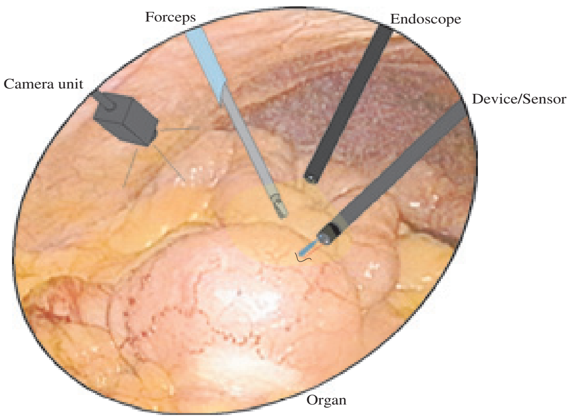



Fig. 14. Concept image of the evolution of the broad-view camera system

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

3. Through our in vivo animal experiments simulating a laparoscopic surgery, we confirmed that the usability of the developed camera unit is higher than that of a conventional endoscope.

## VI. ACKNOWLEDGMENTS

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