Development of New Augmented Reality Function Using Intraperitoneal Multi-view Camera

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Abstract. We developed a multi-view video camera system that works inside the abdominal cavity to obtain a wider range of information during laparoscopic and robotic surgery. This video camera system is able to enter the abdominal cavity and surround an organ in a fixed degree. We conducted in vitro and in vivo experiments to clarify the functions of the system. The advantage of the system is that it can alter the viewpoint without physically moving the camera and can obtain diversified intraperitoneal information. Moreover, by taking advantage of its video image array with geometrical regularity, we build a novel augmented reality function compared with the images for conventional navigation surgery.

Keywords: Multiple-viewpoint camera, Laparoscopy.

1 Introduction

Although more than 20 years have passed since laparoscopic surgery was first developed, intraperitoneal images have not undergone much change. Image quality has improved due to the spread of high-definition video images, but there are still various restrictions to images captured by the lens at the tip of a long tubular laparoscope. This is because the laparoscope itself has a limited field of vision and restriction in the direction in which it can see [1], [2]. As a result, the surgeon must operate in a restricted and narrow field of view. This may lead to the surgeon to not notice bleeding. Intraperitoneal accidents, in which the surgeon damages soft tissue with a surgical instrument because of a limited operative view, occur even to this date. For the same reason, second surgeries due to overlooking ruptured sutures and ligation failure have been reported [3-5]. This is one reason why we did not obtain intraperitoneal image information from a laparoscope. Instead, we positioned a group of cameras to obtain intraperitoneal image information. By taking this approach, we attempted to formulate a new augmented reality that allows for utilization of the attributions of image information. We verified of the function with extracted organ and animal experiments. We herein report on our development.

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2 Method

2.1 Structure of Multi-faceted Camera and Prototype

A laparoscope's field of view is limited because it can only be set intraperitoneally in a conic shape with the trocar in the center [1]. The space inside the abdominal cavity can be widened by insufflation, but the organ and the tip of the laparoscope are sometimes too close, which results in a restricted view of certain parts of the organ. Our concept is to acquire views from multiple directions at the same time by positioning geometrically aligned small-size video cameras. Preceding studies and patents have captured operational field images from multiple viewpoints by attaching multiple cameras at the tip of the endoscope [6], [7], but these do not have structures that can film target organs from multiple directions.

We aimed to deploy a new augmented reality function that obtains multiple types of information. This is in addition to geometrically aligned camera groups that obtain various viewpoints without physically moving during laparoscopic surgery. To realize this concept, we developed a group of small-size cameras that are positioned in a fixed degree surrounding the target organ in an arc. We previously developed a method that positions 60 video cameras in a circle to analyze human full body motion [6-8]. Although the size differs, we aimed to apply the method obtained from this past experiment to the present multi-view camera. We decided to position 5 to 8 cameras in the abdominal cavity considering the size of current video camera devices.

It is impossible set up a group of multi-view cameras positioned on an arc with a radius of 50 mm or more through a trocar with a 10-mm diameter. Therefore, the camera assembly was divided into left and right parts and has a collapsible structure as shown in Figure 1. It is transformed into a bar-like shape to go through the trocar and reach the abdominal cavity. Figure 1 shows its basic structure. The camera group can be repositioned into an arc inside the abdominal cavity by pulling wires outside the body through the trocar. It has a geometrical structure so that each unit mounted with a small-size camera element links with a unit next to it by the pull of the wire to make an arc. After surgery, the surgeon loosens the wires for deployment and pulls them to fold the camera group and return it to its original bar-like shape so that it can exit the abdominal cavity through the trocar.

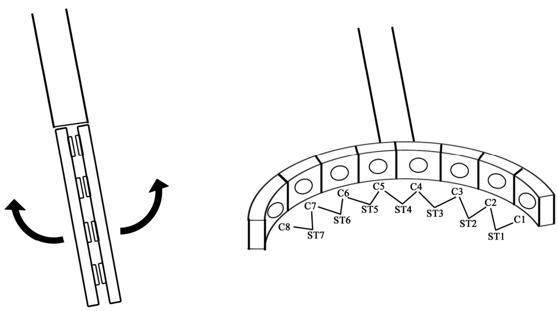

Fig. 1. Basic structure of multi-view camera

The prototype for the animal experiment comprised a multi-view camera that mounted video camera elements (maximum resolution, 1280 × 960) (Figure 2) on 50- to 70-mm-radius arcs. Electric circuits to drive each video camera element were collected onto a substrate. Light sources for each camera could be positioned on the substrate, providing even lighting for the target organ.

Wiring from the substrate in the back of each camera assembly by a flexible cable reduced the volume of cables for the electrical power source and signal lines to the substrate. This helped to miniaturize the camera assembly in the abdominal cavity. Accuracy of the device can be maintained through calibration inside the body after it is deployed even when geometric error occurs in camera array due to loosening of the wires that make up the arc or by soft tissue fragments being caught between movable parts.

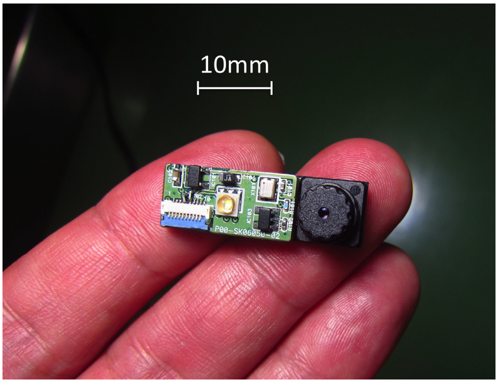

Fig. 2. Form and size of camera module used in prototype system

2.2 New Visual Information and Formulation of Less Restricted Augmented Reality

Obtaining Free Viewpoint in the Abdominal Cavity. By choosing viewpoints from 8 video cameras positioned in an arc when viewing a target object intraperitoneally, the surgeon is able to change the viewpoint without physically moving the camera inside the abdominal cavity. Because each camera drives independently, the surgeon can also monitor all of the viewpoints to understand the entire situation inside the abdominal cavity from various directions by multiple monitors. Moreover, by taking advantage of viewpoints of cameras situated next to each other, stereoscopic viewing is possible. The surgeon is able to choose stereoscopic images randomly from the n-1 direction versus a number of camera viewpoints (n). The surgeon can also obtain stereoscopic view without physically moving the cameras.

Superimposed Display of Organ Structure Using Augmented Reality. This augmented reality function enables the surgeon to recognize structures under the organ surface that cannot be seen grossly by superimposing structures of vessels and tumors in the target organ obtained by X-ray CT and MRI before surgery onto intraperitoneal images obtained from multi-view cameras. Thus, it is also equipped with a navigational surgery function. Moreover, this function takes advantage of a free choice of viewpoint from multi-view cameras. It is able to superimpose images without physical movement of the cameras. During image processing, 2 cameras take in image signals continuously by a switcher to realize a stereo image function. Using these 2 time-sequential images from neighboring viewpoints, stereo-paired overlaid images of intra-organ structures are produced. That is, real-time stereo-paired overlaid images for the left and right eyes are produced by compositing surface-rendering models of vessels and tumors that are simultaneously reconstructed according to each viewpoint. Figure 3 shows the device composition of this function.

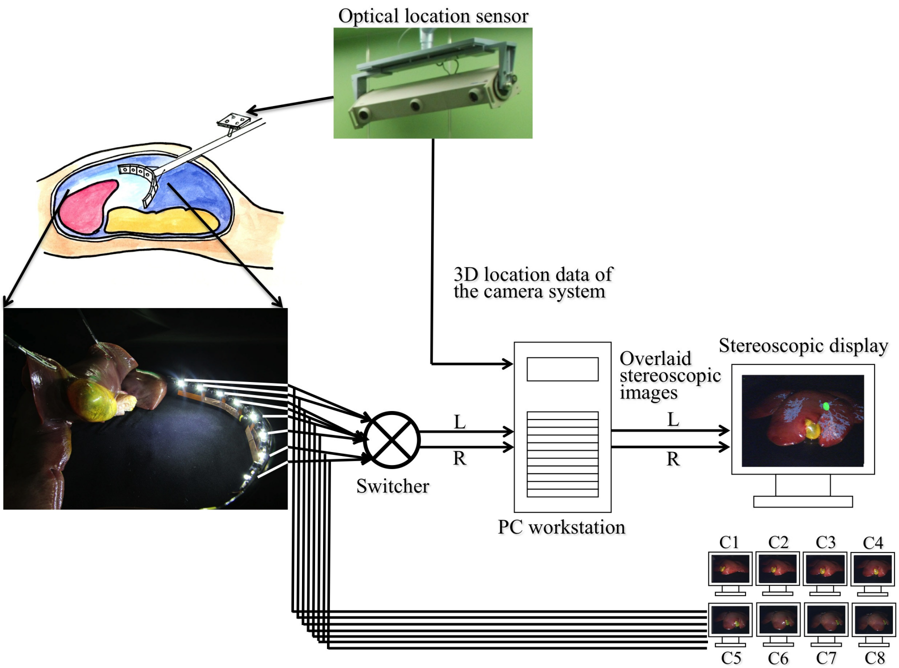

Fig. 3. Device composition of the system

3 Results

3.1 Obtaining Free Viewpoint and Stereoscopic Images

The figures show images taken from viewpoints of 8 directions using extracted liver and gall bladder. Figure 4 shows the setup of the experiment. Figure 5 shows images obtained from each viewpoint. The position of the image matches the number on the camera. As a result, we were able obtain 640 × 480 images in 30 frames/sec from 8 points in a 160-degree direction surrounding the target part. This confirmed that we were able to observe surgical organ conditions with a less restricted view without physically moving the camera inside. It also displayed viewpoints on the main monitor

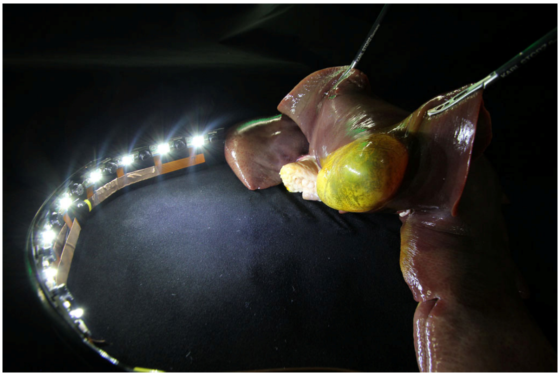

Fig. 4. In vitro experiment using extracted pig liver and gall bladder

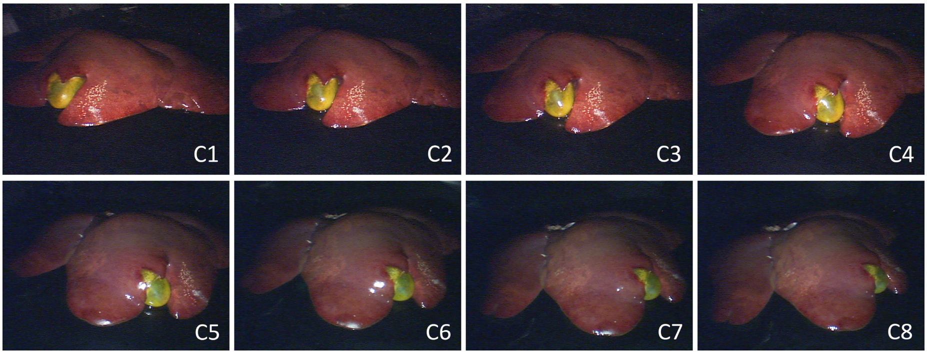

Fig. 5. Images obtained from each viewpoint when the camera system surrounded the extracted pig liver and gall bladder

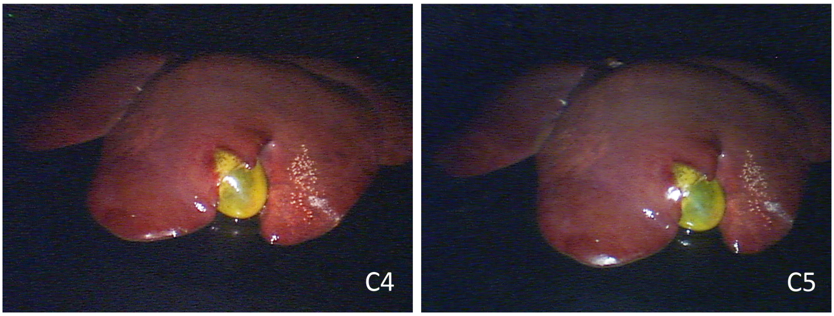

Fig. 6. Stereoscopic images from a viewpoint when the camera system surrounded the extracted pig liver and gall bladder

arbitrarily selected by the control unit. We enabled images from all 8 monitors according to the needs of the surgeon. These were able to be displayed on the submonitors. Figure 6 shows stereoscopic images chosen from 2 camera images next to each other; they were used as the right- and left-eye views, respectively.

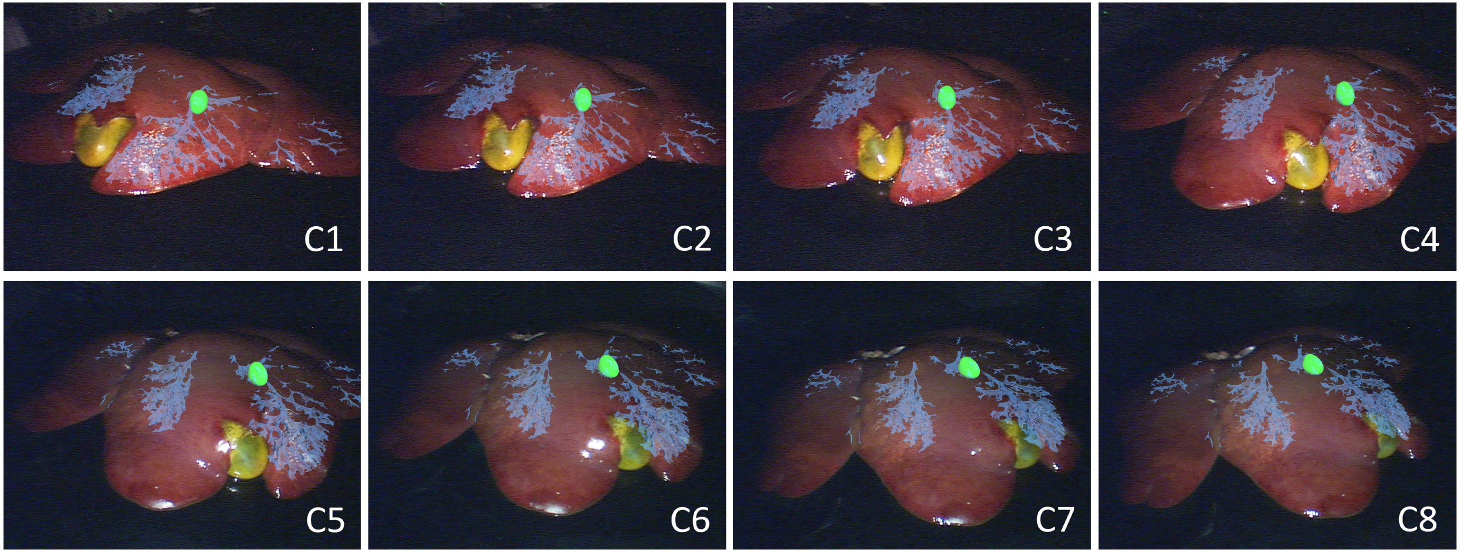

Fig. 7. Superimposed display of images obtained from each viewpoint of part of the vessels and artificial tumor inside extracted pig liver

3.2 Superimposed Display of Inner Organ Structure Using Augmented Reality

Figure 7 shows a superimposed display of intraperitoneal images using a surface model by carrying out segmentation of a part of the vessels and artificial tumor inside a liver from CT datasets obtained in advance with extracted organs of a pig. By utilizing the characteristics of the system, we were able obtain superimposed display images of the position and shape of the vessels in the organ and artificial tumor without physically moving the camera. We also displayed images from all 8 cameras according to the needs of the surgeon on submonitors, and we studied their applications. Figure 8 shows stereoscopic images obtained from cameras C4 and C5, situated near the center of the camera assembly arc. They show the surgeon bringing laparoscopic surgical forceps close to the artificial tumor depending on the superimposed display images. The stereoscopic images were taken at a frame rate of 26 to 29 frames/sec. They were displayed by delay of several frames. Although the frame rate slowed to 1/4 when superimposed images were displayed from 7 directions, we were able to display them simultaneously.

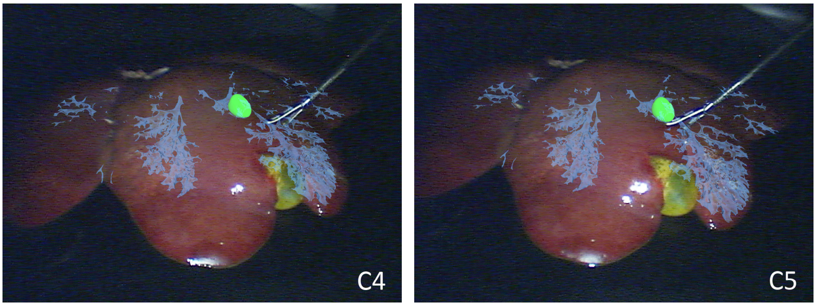

Fig. 8. Stereoscopic images from adjacent cameras (cameras 4 and 5) showing part of the vessels and artificial tumor inside extracted pig liver. Surgeons bringing laparoscopic surgical forceps close to the artificial tumor depend on these superimposed display images.

3.3 Obtaining Intraperitoneal Images from Animal Experiment

We conducted an in vivo verification experiment of the function of the system. Using 4 pigs weighing 35 to 40 kg, we inserted this system into the abdominal cavity under anesthetic conditions. Figure 9 shows image groups of the upper part of the abdomen (superior direction) from 5 viewpoints taken from the bottom part of the abdomen. Each image is provided at 30 frames/sec to the operator. Figure 10 shows the forceps being used from each viewpoint.

Fig. 9. Image groups taken from the bottom part to the upper part (head region) of the abdominal cavity from five viewpoints. Images are from pigs under anesthetic conditions in vivo.

Fig. 10. Images of forceps being used in the abdominal cavity in a pig under anesthetic conditions from various viewpoints

4 Conclusion

We developed a prototype of a camera size that can be used in the abdominal cavity. We evaluated the system using isolated organs and animal experiments. In the in vitro experiment using extracted liver with gall bladder, we confirmed information obtained from the developed system. We were also able to evaluate the application of image information obtained from cameras surrounding the target parts.

The most important function of this system is that it can change viewpoints without physically moving the camera. This prevents clashes of laparoscopes and soft tissue in areas where conventional laparoscopes cannot see and achieves safe camera maneuvering. Conventional laparoscope images are limited to panning of the camera in a cone that centers on the trocar and limits sweet spots, significantly restricting optimum viewpoints. This system views the inner landscape from the target part, which enables views of various sweet spots. It is also able to view target parts from various viewpoints, which allows for different kinds of observations that are not possible using conventional methods. Thus, the surgeon and assistant can respectively choose the viewpoints they wish to see on the monitor. Moreover, they can see all viewpoints from all directions simultaneously using submonitors. The system also has a stereoscopic view function. They can also choose observation points from stereoscopic images from the n-1 direction. These functions, which enable operators to choose their viewpoints in the abdominal cavity, can provide vision information that may lead to new types of surgery. Functions of inner organ structure that are displayed by augmented reality and superimposed displays of planning data may also provide new visual information. We believe that these superimposed displays from various viewpoints without moving the cameras will increase the safety and speed of operations. By creating a prototype and evaluating its functions, we demonstrated that we are able to bring new viewpoints to laparoscopic surgery by obtaining unlimited viewpoints without physically moving the cameras. We also confirmed that adding depth to the field of view enables a safer operation.

We plan to develop a function that enables three-dimensional construction of the operational field by capturing continuous images of the field in a determined space of time. We are also considering mounting a feature inside the system that will update 4-dimensional information of the change in the operational field. This will be of use in evaluating accidents and evaluating the skill level of the operators. We plan to enhance the function of the control unit and create a system that can be used for clinical testing.

We think the system can be applied for clinical application in surgery in wide areas of the abdominal region including conventional laparoscopic surgery in the liver, pancreas, and colon. We also think we can provide various kinds of visual information to the operator for SPS type surgical robot. In addition we expect that in the future as we proceed with the development, it will be possible to mount the system on NOTES type robot which has a flexible structure.

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