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Development and fundamental evaluation of flexible viewpoint laparoscope using a oblique viewing laparoscope

Y. Fukushima, E. Kobayashi, T. Ando, I. Sakuma, *Member, IEEE*

Abstract— **We have developed a new type of laparoscope with flexible view point. This system can move the view without moving laparoscope itself. To achieve the wide range of view moving, we used a commercial 30° oblique-viewing laparoscope and special lens. The system control the view by rotating the oblique-viewing laparoscope and a sleeve which is attached to the special lens by motors independently.**

From the evaluation experiments, we confirmed the laparoscope which has 70° view angle could move the view ±60°. In the image quality evaluation experiment, degradation of the image quality was small. The positioning accuracy was 2.4±1.7mm repeatability was 0.48mm which lead to precise view control. The system achieve the safe and smooth manipulation of the laparoscopic view.

I. Introduction

Recently, laparoscopic surgery is very popular as minimally invasive surgery. In this surgery, laparoscope should be moved to change the operating scene. A rigid type laparoscope should rotate around the insertion point and a flexible type laparoscope should bend at the tip of it to change the view. However, these movement requires moving area in internal body, and therefore it is difficult to change the scene in narrow space and also it has risk to hit organs.

Several endoscope which can move the view without moving itself have been developed. Kamiuchi et. al developed a beam-splitter-type 3-D endoscope which can switch the front view to front-diagonal view by simply rotating its sleeves for fetus surgery[1]. However, this system can show only front view and side view and it can not change in a continuous field of view. Sekiya et al. proposed the wide angle view laparoscope using a fish-eye lens with 120° view angle and prism to cut the field of view[2]. However, image distortion of the Periphery of the visual field was big. There is also a commercialized variable view endoscope system. EndoCAMeleon (ECAM; Karl STORZ GmbH & Co. KG, Tuttlingen, Germany) can move the view from 0° to 120° [3][4]. It can also change the view only discontinuously and the camera assistant need to learn the camera control because rotate and tilt movement should be done independently.

To solve these problems and to achieve the continuous view movement, wide moving view and easy controllability, we have developed the laparoscope with flexible view point using wedge prisms[5][6]. In our first prototype, we put two wedge prisms at the tip of the laparoscope and change the view by rotating the prisms. The view control was performed by two motors and smooth manipulation was achieved. However, in this system, moving range was only ±14.5° for the laparoscope whose view angle was 70°. Therefore, surgical application which this system can be applied to was limited.

From these background, we have developed a new type of laparoscope with flexible view point which has wider moving view range. In this paper, we describe its design, developed prototype, and results of fundamental evaluation experiments.

II. Materials and Methods

A. View moving mechanism

To achieve wide view moving, we used a 30° oblique-viewing laparoscope and put special lens which bend the view 30° at the tip of the laparoscope. The oblique-viewing endoscope and the special lens is rotated independently by motors. By combination of the rotation angle of the laparoscope and the lens, surgeon can move the view to the desired direction.

Here we explain about the lens design. The light was refracted at the two borders of glass and air of a lens. We assumed that the laparoscopic view was pin hole camera model and it emits the light at the interval of 2.5° in 70° view range. Then by ray tracing method, we decide the curved surface to refract all lights to 30° (Fig.1). We also approximate this curved surface by a spherical surface. Figure 2 shows the lens we designed. We used 30°oblique-viewing laparoscope whose diameter was 4mm. Size of the lens was 5 x 5 x 3.5 mm.

Figure 3 shows the total design of the laparoscope with flexible view point. To move the view to the desired direction, the oblique-viewing laparoscope and the special lens are rotated independently by motors. One motor is set at the end of the endoscope and rotate it via gears. The other motor rotates a stainless sleeve and rotate the lens via 30° inclined bevel gear, because the lens should be rotated around the axis of 30° inclined optical axis of the oblique laparoscope.

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Y. Fukushima, E. Kobayashi, T. Ando and I. Sakuma are with School of Engineering, the University of Tokyo, 113-8656 Japan (corresponding author to provide phone: +81-3-5841-6480; fax: +81-3-5841-6480; e-mail: etsuko@ bmpe.t.u-tokyo.ac.jp).

S. B. Author, Jr., was with Rice University, Houston, TX 77005 USA. He is now with the Department of Physics, Colorado State University, Fort Collins, CO 80523 USA (e-mail: author@lamar. colostate.edu).

T. C. Author is with the Electrical Engineering Department, University of Colorado, Boulder, CO 80309 USA, on leave from the National Research Institute for Metals, Tsukuba, Japan (e-mail: author@nrim.go.jp).

Figure 4 shows the picture of the laparoscope. Diameter and length of the sleeve were 20mm and 170mm respectively. The size of motor box was 250 x 130 x 100mm.

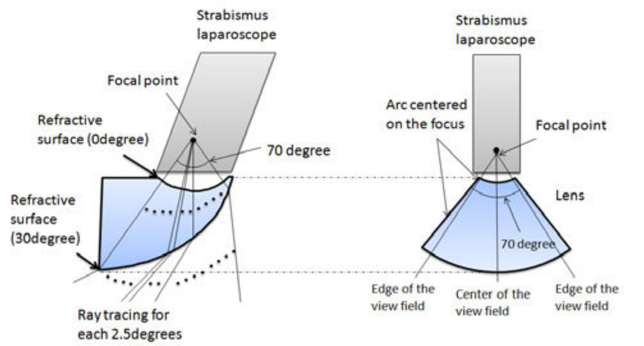

Figure 1. Design of the lens: we assumed the laparoscopic view was pin hole camera model and it emits the light at the interval of 2.5° in 70° view range. Then by ray tracing method, we decide the curved surface to bend all lights to 30° .

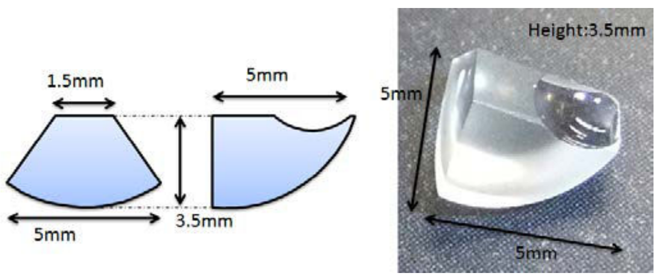

Figure 2. View of the lens that we designed

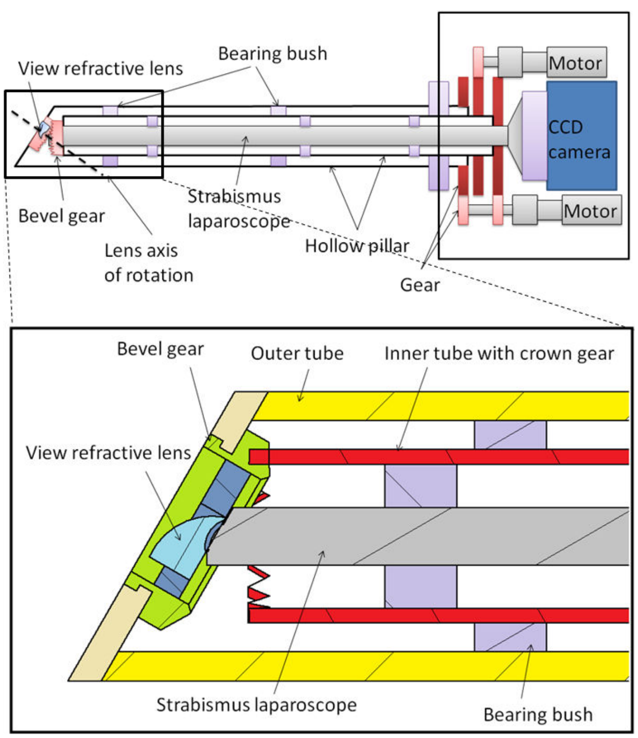

Figure 3. Mechanical design of the flexible view point laparoscope

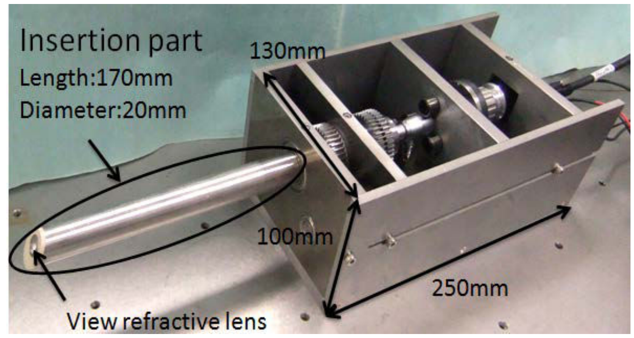

Figure 4. Picture of the laparoscope with flexible view point

B. System Configurations

Figure 5 shows the system configuration. We used two DC motors (NC-155702, Citizen Chiba Precision co. ltd.) and controlled them by PC using a motor control board (PCI7414, Interface co. ltd.). Resolution of a CCD camera (Guppy PRO F-125, ALLIED Vision Technology) was 1292 x 964. The image was captured by an image capture board (IEEE1394b-PCI) and displayed on a monitor. Because the laparoscope was not mounted light guide, an external light was used. For future, we will built the light function build in the laparoscope as commercial laparoscope. Specifications of the oblique-viewing laparoscope, motor and CCD camera are shown in TABLE I.

Position of the view is determined by rotation angle of the lens and the oblique-viewing laparoscope. Its relationship is calculated by Snell's law. Surgeon input the desired direction among up sown right and left directions. Then the computer calculate rotation angle to achieve its movement. It took 6 sec to move the view from center to the corner. Fig. 6 shows the center and side view of the laparoscope.

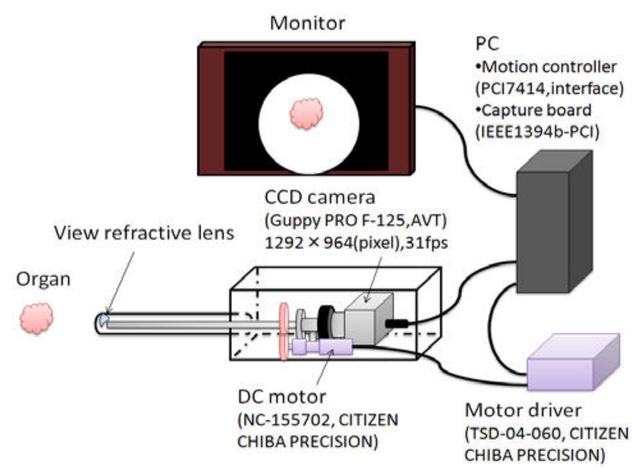

Figure 5. System Configurations

TABLE I Specifications of the oblique-viewing laparoscope, mo tor and CCD camera

(a) Oblique-viewing laparoscope (Shinko-Optical)

View range	Oblique angle	Length	Diameter
70 deg	30 deg	250mm	4 mm

(b) DC motor (NC-155702, Citizen Chiba- Seimitsu)

Rated power	Rated Torque	Rated Speed
5.3W	6.37 mNm	8200 rpm

(c) CCD Camera (Guppy Pro F-125)

Resolusion	Frame rate
1292 x 964	31 fps

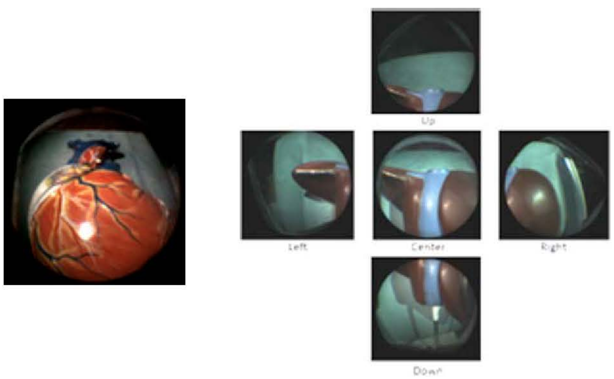

Figure 6. View of the laparoscope. Left: center view of a heart model. Right; center, up, down, right and left direction of liver model.

III. RESULTS

A. Image quality evaluation experiment

A resolution chart was set 50 mm in front of the laparoscope. We measured the minimum line width which can be observed in the center view by the oblique-viewing laparoscope with and without the special lens. The measurement was performed at center pert and upper part in a view.

TABLE II shows the results. Minimum line width of vertical stripes which was observed at the center part of the center view was 0.36 mm and horizontal stripes was 0.4 mm. On the other hand, minimum line width of horizontal stripes which was observed at the upper part of the center view of the flexible viewpoint laparoscope was 0.71 mm. The degradation of longitudinal resolution was observed at the upper part of the view.

B. Moving view range

We designed the laparoscope to move the view ±60° by using the 30° oblique-viewing laparoscope and the special lens to bend the view 30° . In this experiment, we confirmed the moving view range of our prototype.

A sphere with radius of 75mm was set in front of the laparoscope. Scale in increments of 10 degrees was written inside the sphere. The tip of the laparoscope was set at the center of the sphere. In the inside of the sphere, the scale of the angle was written. We measured the center position using this scale, when the center view and upper view were observed. As a result, the moving range of the view was from 10° to 60° (Fig.7). With the same method, we measured the moving view range in down, right and left directions. As a result, the moving range of the view was from 10° to 60° in all directions.

TABLE II Minimum line width which can be observed in the center view by the oblique-viewing laparoscope with and without special lens (mm)

	Center pert		Upper pert	
	Vertical stripes	Horizontal stripes	Vertical stripes	Horizontal stripes
Oblique viewing laparoscope	0.31	0.31	0.45	0.56
Oblique viewing laparoscope with the lens (Flexible view point laparoscope)	0.36	0.4	0.45	0.71

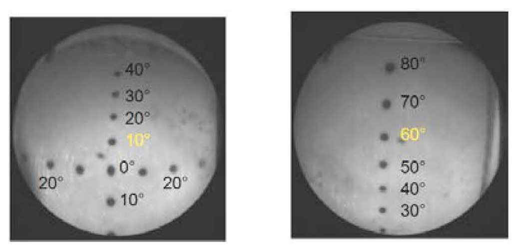

Figure 7. Center view (left) and upper view (right)

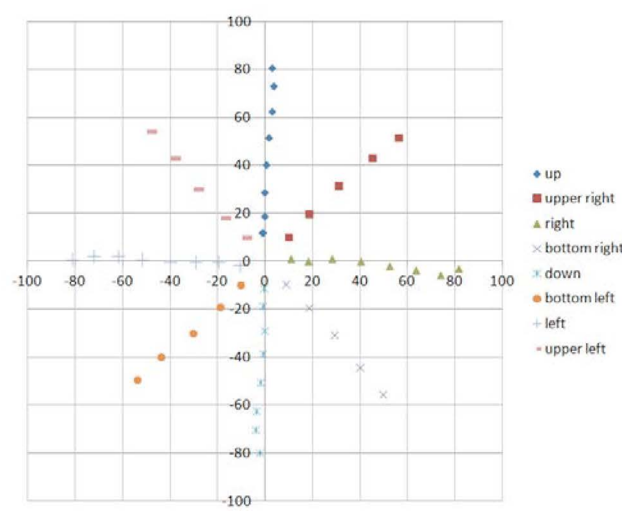

Figure 8. Results of positioning accuracy of the view when moving eight direction.

C. Positioning accuracy

A cross section paper was set 50mm in front of the laparoscope and we moved the view from 0 mm to 80 mm in increments of 10mm to eight directions. Then we measured the position accuracy of the view.

Results show in fig.8. The positioning error was 2.4± 1.7mm at every position. Average of repeatability of each position was 0.48mm.

IV. Discussion

As a result of image resolution evaluation experiment, deterioration of resolution of horizontal stripes at the upper part of the screen was relatively large. The main reason of it was image distortion caused by bending the field of view. Figure 9 shows the view of the grid spacing taken 5mm. Bigger image distortion was observed at the upper part of the view. Optimal lens design have to be performed to eliminate it . On the other hand, the deterioration of image resolution of center part was low. This point is very important because surgeons normally concentrate on watching center part of view. We also have to evaluate that image quality of the laparoscope is capable or not.

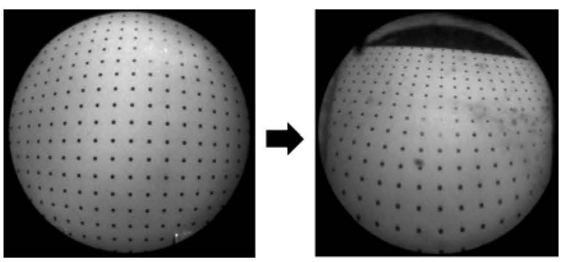

Figure 9. Image distortion of the laparoscope. Left: view of the commercial oblique-viewing endoscope. Right: View of the new flexible viewpoint laparoscope.

Moving view range was from 10° to 60 ° in upper, downer right and left direction. It was enough moving view range to observe the abdominal cavity. However, one drawback of this endoscope is that it can not move the view within ±10 ° . It should be also solved by optimal lens and manipulator design.

Positioning accuracy was 2.4 ± 1.7mm and average of repeatability was 0.48mm. We consider this error is capable because precise positioning is not required in the view moving. The main reason of the error was assembly error of the lens. By calibrate the motor output and actual view position, more accurate positioning will be achieved.

The diameter of the endoscope was 20mm which was bigger than the commercial endoscope. Since the diameter of the lens was 5mm, endoscope diameter could be as small as 12-15 mm. by changing the size of a sleeve and gears. In this prototype, we used commercial oblique-viewing laparoscope. By designing the oblique-viewing laparoscope itself, additional downsizing would be achieved.

The main advantages of this system are as follows. First the laparoscope never move itself to move the view, it is totally safe since there is little possibility to hit organs. Also it can be used at narrow space. The advantage compare to commercialized flexible type laparoscope is that the laparoscope can easily change the camera. Now new high quality cameras such as high resolution camera and ultra-sensitive camera have been developed. The laparoscope can be easily attached to these cameras with little degradation image quality.

In this research we performed fundamental evaluation experiment. In these evaluation, we confirmed the degradation of image quality is small and moving range was ±60° . In the next step, we improve the system to be small size and sterilizable and to add light. We will verify the effectiveness on a animal experiment.

V. Conclusion

We have developed the prototype of new type of laparoscope with flexible view point. By using the commercial oblique-viewing laparoscope and special lens, ±60° view moving was achieved. In the image quality evaluation experiment, degradation of the image quality was small in the center part of the view. The positioning accuracy was 2.4± 1.7mm repeatability was 0.48mm which lead to precise view control. The system provide a safe and smooth manipulator of the view.

In future work, we improve the system and perform the animal experiment to achieve the clinical use

Acknowledgment

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