Development of a Laparoscopic Surgery Training System and Preliminary Experiments

Hirokazu MASUGAMI*, Tomohiro KAWAHARA*, Hiroyuki EGI**
Masanori YOSHIMITSU**, Masazumi OKAJIMA** and Makoto KANEKO*
*Graduate School of Engineering, Hiroshima University
**Graduate School of Biomedical Science, Hiroshima University
masugami@hfl.hiroshima-u.ac.jp

Abstract

This paper discusses the direction dependent dexterity of surgeons in laparoscopic surgery. In laparoscopic surgery, a surgeon can observe the concerned tissue only through a 2D display and is obliged to convert the image from 2D to 3D in his (or her) brain. In this report, we examine the effect of 2D or 3D visual information on the manipulation dexterity by utilizing the newly developed evaluation system.

1 Introduction

Laparoscopic surgery is a well established method in modern medicine. In laparoscopic surgery, a surgeon inserts forceps and a scope into the abdomen through small holes, so no large cuts are necessary as in open surgery. It is a method in minimal invasive surgery. It was well examined scientifically that it does not affect a life prognosis, and has a similar rate of cures for malignant diseases[1][2][3].

On the other hand, many reports in operation mistakes by laparoscopic surgery are seen in the news in recent years. In order to prevent such operation mistakes, the education to surgery residents is necessary. In laparoscopic surgery, as shown in Fig.1, surgeons have to operate forceps, looking at a monitor, without seeing the affected part directly, and have to convert the image from 2D to 3D in their brain.

The purpose of this study is quantifying the direction dependent dexterity of surgeons in laparoscopic surgery. In this paper, we analyze how a surgeon obtains a distance feeling for the depth direction while converting the 2D display image to a 3D space. Then, we show that the image conversion capability to 3D can be considered as an element to judge a surgeon's skill.

2 Related research

There are many reports that evaluate laparoscopic surgical skills. Although Kopta[4] presented methods to evaluate surgical skills, they are not widely accepted. Martin[5] and others made an evaluation system called Objective Structured Assessment of Technical Skill (OSATS), which gained consensus for the first time based on its excellent objectivity. Moreover, Rosser, et al.[6][7][8][9] claimed what makes laparoscopic surgery difficult is the limitation of the

Fig.1: Overview of Laparoscopic Surgery

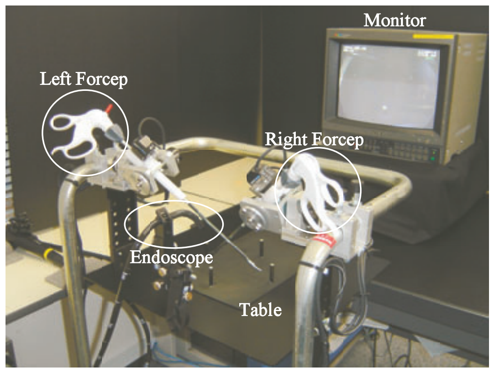


Fig.2: Overview of the Developed System

spatial information due to the 2D display, and supported their claim by monitoring the learning effect by change of performance time. Most of these reports evaluated the improvements in reaching the training goal, which had not been necessarily quantitive. However, recently, the tip position of forceps is measured, and thus the number of test methods using quantitive analysis about the operation increases. Cuschieri, et al. developed the Advanced Dundee Endoscopic Psychomotor Tester (ADEPT) which acquires the forceps tip position information by using an encoder[10][11]. Darzi, et al. developed the Imperial College Surgical Assessment Device (ICSAD) which acquires the forceps tip position information by using an electromagnetic field, and utilizes it effectively to improve laparoscopic skills[12][13][14]. Sokollik, et al. considered the tip speed profile from the forceps tip position data by the ultrasonic sensor[15]. Also, there are simulators that perform the analysis and evaluation of the

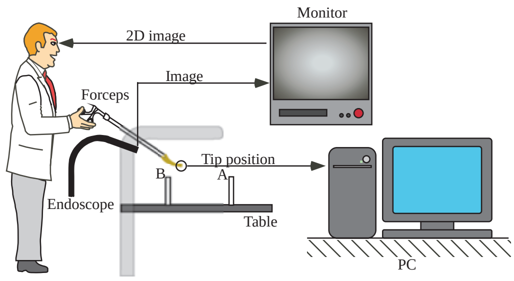


Fig.3: System Architecture

position information by vision sensors[16] and others that use a virtual reality to simulate an actually undergoing operation[17].

Here, the image conversion capability from 2D to 3D is considered as one of the necessary skills in laparoscopic surgery. We focus on the distinction between the vertical movement and the front-and-back direction movement, as it is regarded as being very difficult.

3 Materials

3.1 The feature of the developed device

Fig.2 and Fig.3 show the experiment device and the system architecture. As can be seen from Fig.2, the endoscope is installed in front of a table and the 2D image is shown on the monitor. A gimbals mechanism is used in this system to grasp the forceps. Two encoders are attached to the two rotational axes. In addition, we fixed a scale seal (LBP = 0.1[mm]) on the stem part of forceps, in order to be able to acquire the displacement of the length. Then, we used the heat shrink tube to secure the seal on the stem. Furthermore, the opinion of surgeons was taken into account. In order to reproduce the load felt in an actual operation, we used a spring mechanism that enables to adjust rotation friction of the gimbals. Furthermore, in order to prevent the candidate to look at the subject directly, instead of the monitor during an experiment, we manufactured a cover made of a black plastic plate. Fig.3 shows the information flow of this system by arrows.

3.2 The forceps tip position detection method

We can measure the two rotation angle parameters and one distance parameter by using three encoders. As shown in Fig.4, by measuring the three parameters l, θ and ϕ, the relative position coordinates $x = l \cdot \sin\phi$, $y = l \cdot \cos\phi \cdot \sin\theta$ and $z = -l \cdot \sin\phi \cdot \cos\theta$ of the gimbal central point can be calculated.

3.3 Position detection accuracy

We acquired the position data for both tips by putting the tip of the forceps on pre-defined 14 points on the table that were separated by 50[mm]. Then, we investigated the deviation from the true value when acquiring position information for the 14 points of the two tips 10 times. As shown in Fig.5(a), the maximum error was 6.20[mm], the average error was 2.54[mm], and standard deviation 1.28[mm].

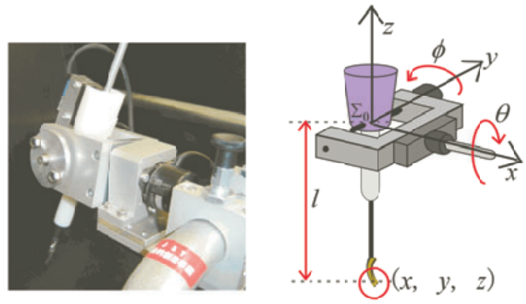


Fig.4: Coordiate System

Then, we considered the error due to alignment, and corrected it by the method shown in the following paragraph. As a result, the maximum error was 3.23[mm], the average error was 0.92[mm], and standard deviation 0.62[mm] after the correction as shown in Fig.5(b). Thus the position accuracy was greatly improved. The circles of Fig.5 shows the average error before and after compensation, respectively.

3.4 Compensation method

In a first step of the compensation method of the system, the three points v_{t1}, v_{t2} and v_{t3} were chosen as calibration points and their true x-y-z values are known. Next, using v_{t1} as a reference point, the position data on the remaining points v_{t2} and v_{t3} is acquired by the parameter from each encoder of the system and the equations $x = l \cdot \sin\phi$, $y = l \cdot \cos\phi \cdot \sin\theta$, $z = -l \cdot \sin\phi \cdot \cos\theta$. Then, the deviations Δv_2, Δv_3 of the acquired values v_2, v_3 from the true values v_{t2}, v_{t3} were derived from the equations:

$$v_{t1} = v_1 \quad (1)$$
$$v_{t2} = v_2 + \Delta v_2 \quad (2)$$
$$v_{t3} = v_3 + \Delta v_3. \quad (3)$$

As is commonly known, the arbitrary positions in the 3D space can be expressed as follows by using the three position vectors:

$$v = Vk \quad (4)$$

where $V = [v_1\ v_2\ v_3]$ and $k = [k_1\ k_2\ k_3]^T$.

That is, if v and $V = [v_1\ v_2\ v_3]$ are known, equation (4) can be changed into

$$k = V^{-1}v \quad (5)$$

in order to obtain $k = [k_1\ k_2\ k_3]^T$.

Therefore, $k = [k_1\ k_2\ k_3]^T$ can be found, if v_{t1}, v_{t2}, v_{t3}, v_1, v_2 and v_3 are known beforehand. Also, the true value $\hat{v}_t$ can presume as follows,

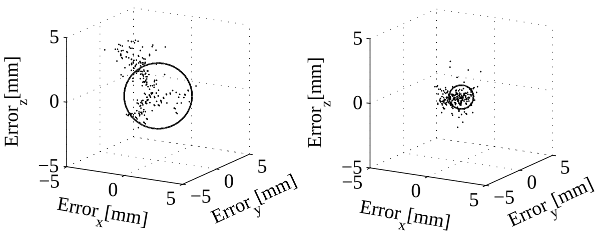
$$\hat{v}_t = v_{t1}k_1 + v_{t2}k_2 + v_{t3}k_3 \quad (6)$$

using equations (1), (2) and (3), equation (6) can be changed into

$$\hat{v}_t = v_1k_1 + (v_2 + \Delta v_2)k_2 + (v_3 + \Delta v_3)k_3. \quad (7)$$

With equation (4), we finally obtain

$$\hat{v}_t = v + \Delta v_2k_2 + \Delta v_3k_3. \quad (8)$$



(a)Before Compensation (b)After Compensation

Fig.5: Position Errors before/after Compensation

4 Preliminary Experiment

4.1 Purpose

This chapter shows that the human characteristic when only on carrying out 3D movements of the forceps relying the information from a 2D display. It is shown that the difference in skill of an amateur and a surgeon is appearant in this setup.

4.2 Methods

In the experiment point A and point B on the table in Fig.3 are 150[mm] apart. The subject was asked to move the forceps tip from point A to point B and back again to point A. The tip position information was acquired during the whole movement.

4.3 Definition of the target point attainment

The attainment times $t_i (i = 1, 2)$ to the intermediate point B and the ending point A are taken when the forceps tip stays with in a distance of $d_g = 3$[mm] from target point for $t_g = 0.3$[s]. They are defined as follows:

$$t_i = \inf \left\{ t_n \,\middle|\, \begin{array}{c} \|p_i - p(t)\| < d_g, \\ t_n - t_g \leq t \leq t_n \end{array} \right\}. \quad (9)$$

Here, $p(t)$ is the forceps tip position vector after t[s] from start, and $p_i (i = 1, 2)$ is a target position vector, respectively. Also, $t_1 < t_2$.

4.4 Results

The experimental results of an amateur and an expert are shown in Fig.6 and Fig.7. They show the tip trajectory in the xy plain (top view) and in the yz plain (side view) in the experiment done by an amateur (Fig.6) and by an expert (Fig.7). Here, looking at both top views, deviation from the ideal trajectory in the side direction is very small. Looking at both side views respectively, a large difference in the deviation in the hight direction of the expert's and amateur's forceps tips trajectory can be seen.

4.5 Discussion

That the different deviations discussed the last paragraph are due to the shortage of the information by a 2D display. A motion in the actual vertical direction and a motion of the front-and-back direction cause a both vertical movement on a monitor, while a motion in the side direction on a monitor corresponds

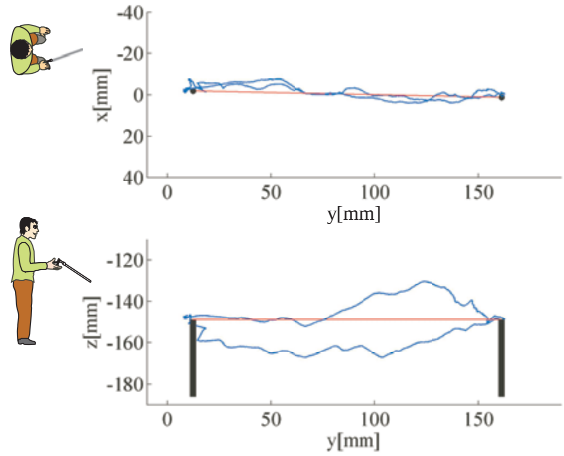


Fig.6: Tip Trajectory of an Amateur

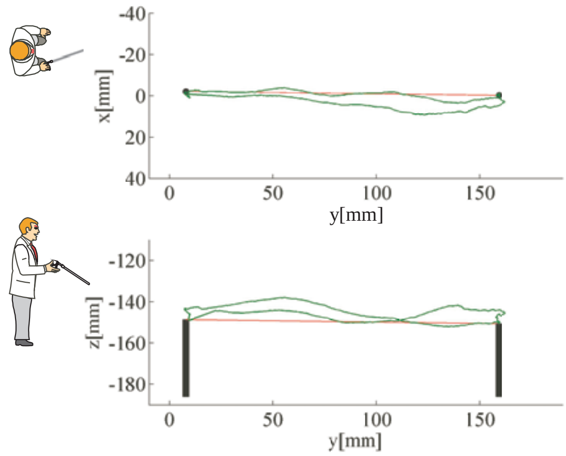


Fig.7: Tip Trajectory of an Expert

to the actual side motion. Therefore, a subject considers the correction of the deviation in the vertical direction difficult, while the correction of the deviation in the side direction is considered comparably easy.

5 Direction dependent dexterity

5.1 Integration according to direction ingredient

In case of the experiment shown in the preceding chapter, it is characteristic deviation of the vertical direction was large, compared to the deviation of the side direction was very small. Here, the deviation in the side direction and the deviation in the vertical direction are integrated over the move distance according to the ingredient. Then, the result of the amateur's tip movement seen from Fig.6, the deviation integration value A_x of the side direction is $A_x = 616.27$[mm^2], and the deviation integration value A_z of the vertical direction is $A_z = 2934.37$[mm^2]. The result of the expert's tip movement seen from Fig.7 is $A_x = 954.99$[mm^2], $A_z = 1347.27$[mm^2].

5.2 Direction dependence line

We express the relation m between the deviation integration value A_x of this side direction and the deviation integration value A_z of the vertical direction as follows.

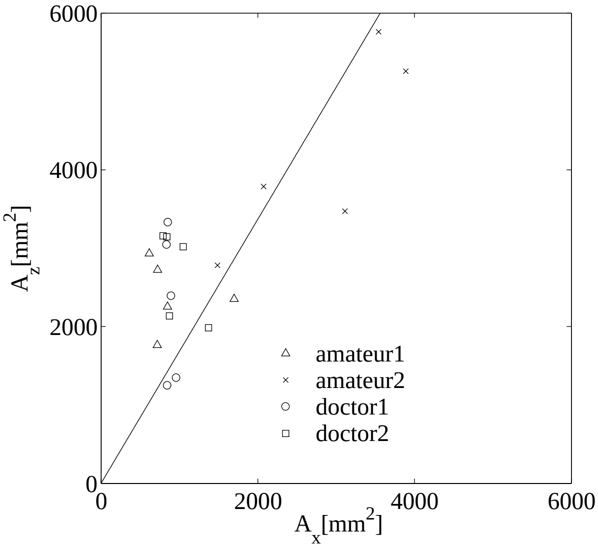


Fig.8: Direction Dependence Line

$$m = \frac{A_z}{A_x}. \tag{10}$$

In order to verify the tendency of a direction dependence in two or more experiment results, we consider the graph which sets the horizontal axis to A_x, the vertical axis to A_z and the inclination to m. Each point in Fig.8 is the result of one of 5 experiments carried out by two amateurs and two experts, respectively. The straight line in the graph marks the direction dependence m obtained by using the least-squares method in the data for these 20 data points. The inclination of the straight line is $m = 1.95$.

Moreover, as can be seen from the graph, it turns out that each point $m > 1$. Thus, the correction of the deviation in the vertical direction is again observed to be more difficult due to the lack of information from the 2D display.

6 Conclusion

In this report, we introduced an equipment for evaluating a doctor's skill in laparoscopic surgery, and described the forceps tip position data acquisition method, and its accuracy. Also, we found that obtaining the distance feeling of the depth direction is very difficult, due to the conversion of information from a 2D display to 3D that the surgeon has to perform in laparoscopic surgery, and conducted the basic experiments. As a result, distinction of the vertical direction and the front-and-back direction from 2D display is difficult. Thus, the direction dependence might be one parameter that shows a surgeon's skill. Furthermore, we defined the characteristics of human operation in endoscopic condition by the direction dependence, and considered its tendency by the results of a preliminary experiments.

In the next step, we will consider the know-how of experts to use one forceps to help to judge the position of the other forceps in the 3D conversion.

Finally, we would express our sincere thanks to Dr. Roland Kempf for his valuable comments.

References

[1] H. Hasegawa, Y. Kabeshima, et al: "Randomized controlled trial of laparoscopic versus open colectomy for advanced colorectal cancer," *Surg Endosc*, vol.17, no.4, pp636-640,2003.

[2] 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, pp2050-2059,2004.

[3] R. Gonzalez, C. D. Smith, et al: "Laparoscopic vs open resection for the treatment of diverticular disease," *Surg Endosc*, vol.18, no.2, pp276-280,2004.

[4] J. A. Kopta: "An approach to the evaluation of operative skills," Surgery, vol.70, no.2, pp297- 303,1971.

[5] J. A. Martin, G. Regehr, R. Reznick, et al: "Objective structured assessment of technical skill (OSATS) for surgical residents," *Br. J. Surg*, vol.84, no.2, pp273- 278,1997.

[6] J. Rosser, L. Rosser, R. Savalgi: "Skill acquisition and assessment for laparoscopic surgery," *Arch Surg*, vol.132, no.2, pp200- 204,1997.

[7] J. Rosser, L. Rosser, R. Savalgi: "Objective evaluation of a laparoscopic surgical skill program for residents and senior surgeons," *Arch Surg*, vol.133, no.6, pp657- 661,1998.

[8] D. Risucci, J. Rosser, et al: "Experience and visual perception in resident acquisition of laparoscopic skills," *Curr Surg*, vol.57, no.4, pp368- 372,2000.

[9] D. Risucci, J. Rosser, et al: "Surgeon-specific factors in the acquisition of laparoscopic surgical skills," *Am J Surg*, vol.181, no.4, pp289- 293,2001.

[10] A. I. Macmillan, A. Cuschieri: "Assessment of Innate Ability and Skills for Endoscopic Manipulations by the Advanced Dundee Endoscopic Psychomotor Tester: Predictive and Concurrent Validity," *Am J Surg*, vol.177, no.3, pp274-277,1999.

[11] N. K. Francis, G. B. Hanna, A. Cuschieri: "Reliability of the Advanced Dundee Endoscopic Psychomotor Tester for Bimanual Tasks," *Arch Surg*, vol.136, no.1, pp40- 43,2001.

[12] K. Moorthy, Y. Munz, A. Darzi, et al: "Motion analysis in the training and assessment of minimally invasive surgery," Taylor & Francis Health Sciences, vol.12, no.3-4, pp137-142,2003.

[13] K. Moorthy, Y. Munz, A. Darzi, et al: "Objective assessment of technical skills in surgery," *BMJ*, vol.327, no.7422, pp1032-1037,2003.

[14] K. Moorthy, Y. Munz, A. Darzi, et al: "Validity and reliability of a virtual reality upper gastrointestinal simulator and cross validation using structured assessment of individual performance with video playback," *Surg Endosc*, vol.18, no.2, pp328-333,2004.

[15] C. Sokollik, J. Gross, G. Buess: "New model for skills assessment and training progress in minimally invasive surgery," *Surg Endosc*, vol.18, no.2, pp495-500,2004.

[16] Haptica: ProMIS, http://www.haptica.com/.

[17] Reachin: Reachin Laparoscopic Trainer 2.0, http://www.reachin.se/.

[18] G. B. Hanna, A. Cuschieri: "Optimal port locations for endoscopic intracorporeal knotting," *Surg Endosc*, vol.11, no.4, pp397-401,1997.

[19] G. B. Hanna, A. Cuschieri: "Influence of the optical axis-to-target view angle on endoscopic task performance," *Surg Endosc*, vol.13, no.4, pp371-375,1999.

[20] G. B. Hanna, A. Cuschieri, et al: "Influence of Two-dimensional and Three-dimensional Imaging on Endoscopic Bowel Suturing," *World J. Surg*, vol.24, no.4, pp444-449,2000.

[21] G. B. Hanna, A. Cuschieri, et al: "Effect of the angle between the optical axis of the endoscope and the instruments' plane on monitor image and surgical performance," *Surg Endosc*, vol.18, no.1, pp111-114,2003.