Evolution of Virtual Training System for Endoscopic Surgery

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ABSTRACT

Currently, the short of endoscopic surgeons has been identified as one of the medical issues in Japan. In order to increase the number of endoscopic surgeons, the training environments have been developed and widely used all over the world. However, neither the functions of correcting wrong operation nor instructing correct operation have been established in the existing training systems. Then, this study aims to develop a VR training system, where a trainee can experience the operation skill of an advising doctor. In this paper, the authors implemented the system validation with inexperienced doctors and skillful doctors. Virtual reality based surgical simulator systems are very elegant approach to enhancing traditional training in endoscopic surgery. This paper briefly introduces the VR training system we have developed and shows the experimental results.
Keywords : Component, Endoscopic Surgery, Virtual System, Surgical Simulator, Endoscopic Camera

I. INTRODUCTION

Recently, endoscopic surgery has been recognized as one of the noninvasive surgeries in Japan. According to the development of surgical device and endoscopic camera, its target domain is expanding gradually; therefore the number of cases has been increasing.

Fig. 1 shows a scene of endoscopic surgery, where the surgeons operate the endoscopic forceps with viewing an intra-abdominal image via 2D monitor. The endoscopic camera and the forceps were inserted in the patient body through the trocars mounted on the patient body surface. Hence, the endoscopic forceps move symmetrically on the position of trocar.

In addition, the stereoscopic visual information of the surgical field disappears in the 2D monitor. These are the features of this operation procedure, and the doctors have been requested to experimentally overcome them before becoming an operating surgeon [7][8].

In the phase of training, it is important for doctors to cultivate the ability to consciously correlate the intra-abdominal image with the forceps operation necessary to complete the procedure. This study has called this ability as the feeling of forceps operation.

At present, a variety of training environments such as a simulator and an animal laboratory have been utilized all over the world [5][6]. Inexperienced doctors are using these training environments on the premise of learning appropriate knowledge and technique of endoscopic surgery by using some instructional text and the movies of operations. However, in order to cultivate the feeling of forceps operation, the authors considered that the functions instructing applicable operation and/or correcting erroneous operation should be mounted in the training environment. By the way, it is difficult for us to transmit the operation skill by using languages to a trainee. In order to facilitate resolution of this issue, this study originally constructed the experimental devices that control the position of trainee's forceps.

In our previous studies, the training system enabled a trainee to repeatedly practice a linear motion of forceps by using the guidance function of the experimental device [1]. And, this study tried to quantitatively evaluate the operation skill of a trainee by the process of recovering from the deviation due to unexpected disturbance. Eventually, we could not find clearly the relationship between the coping ability for unexpected disturbance and the operation skill of a trainee [2]. According to our previous results, this study had to review our strategy to cultivate the feeling of forceps operation.

In this paper, this study aims to establish the function which enables a trainee to experience the feeling of forceps operation of an advising doctor. This study firstly constructed an advising data from the performance of an expert surgeon who performed transfixion suture for a mimic enteric canal sheet. This paper firstly describes a system structure and the method of utilization of our system. Finally, the experimental results with the surgeons will be shown.

Fig. 1 A scene of operation room in endoscopic surgery

II. METHODS

A. System Structure

Fig. 2 shows the training system we have developed in this study. This system is composed of a desktop computer, a dry box, and forceps control devices. An actual endoscopic forces can be mounted at the endo-effector of the forceps control device. The computer is running on Windows 7 (32bit-OS). The development environment is Visual Studio 2013. Both OpenGL and OpenCV are installed to draw virtual forceps on the movie of an advising data.

In this paper, transfixion suture is adopted as the target surgical procedure. Therefore, we mounted a needle-holder (Karl Storz Endoskope, K2617KAF) and a grasping forceps (Olympus， WA64160A, A60800A, A60210A）on left and right forceps control devices, respectively.

This study additionally mounted the linear potentiometers to measure the statement of opening and closing of the grippers as shown in Fig. 3 and Fig. 4. This information is important to inform the rotation angle of the forceps to a trainee. This study originally built the gear boxes and mounted them at the shaft of forceps in order to realize the angle control of the forceps. The DC servo motor with rotary encoder is set in the gear box, that realize the guide function dealing with the motion of rest. The authors considered that this function is helpful to transmit the feeling of forceps operation in training. The movements of forceps were tracked by the web camera mounted on the dry box. In the system, the image of box inside is shown on the monitor.

B. Forceps' Control Device

Fig. 5 shows the forceps control device and its mechanism map. It has three degrees of freedoms and the DC servo motor with rotary encoder is embedded in each joint. From Fig. 4(b), the forward kinematics can be derived as shown in the equations from (1) to (4). And, the inverse kinematics are written as the equations from (5) to (7).

$$l = d2 \cos q2 + d3 \sin q3 \quad (1)$$

$$x = l \cos q1 \quad (2)$$

$$y = l \sin q1 \quad (3)$$

$$z = d2 \sin q2 + d3 \cos q3 \quad (4)$$

$$q1 = \operatorname{atan2}(y, x) \quad (5)$$

$$q2 = a\cos\left(\frac{1}{l^2+z^2} d^3 z\cos(q_2+q_3) + \frac{l(l^2+z^2+d_2^2-d_3^2)}{2d_2}\right) \quad (6)$$

$$q3 = a\sin\left(\frac{l - d_2\cos q_2}{d_3}\right)$$

The variables of q1, q2, and q3 are the rotation angles of each joint. The variable l is the length from the center of device to the end-effector. The length of each link d1, d2, and d3 are 210mm, 230mm, and 270mm, respectively.

C. Utilization Procedure

This training system works with a supervised data. The advantage of this system is that any surgical procedure can be set as the supervised data. In order to make a supervised data, firstly an advising doctor needs to perform the forceps operation. While the doctor performs the forceps operation, the image of box inside and the motion of forceps are recorded as the supervised data, where the motion data of forceps can be derived from the forward kinematics shown in the equations from (1) to (4). In addition, the rotation angle of forceps is measured by the rotary encoder mounted in the gear box.

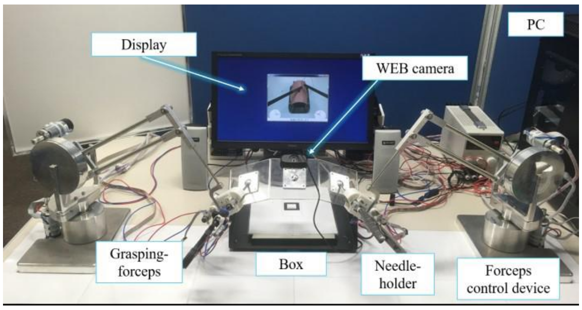


Fig. 2 System structure for endoscopic surgery

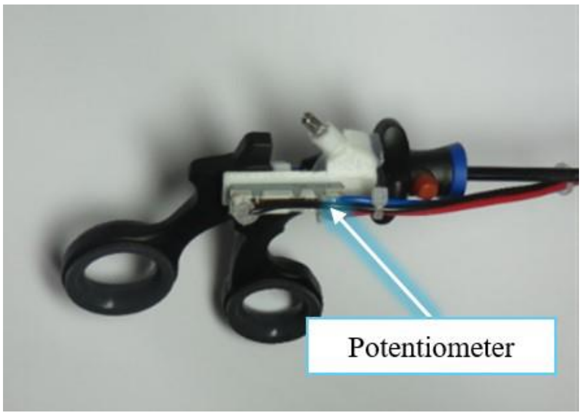


Fig. 3 Potentiometer mounted on the hand gripper of holding forceps

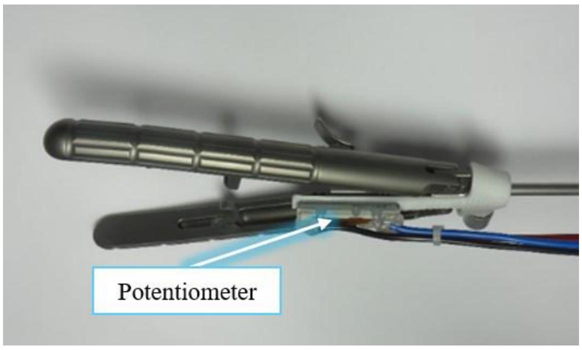
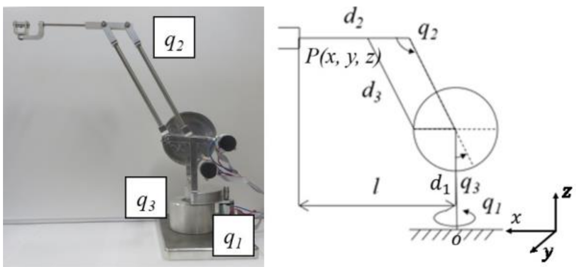


Fig. 4 Potentiometer mounted on the hand gripper of needle-holder



(a) Overview (b) Mechanism map

Fig. 5 Forceps control device

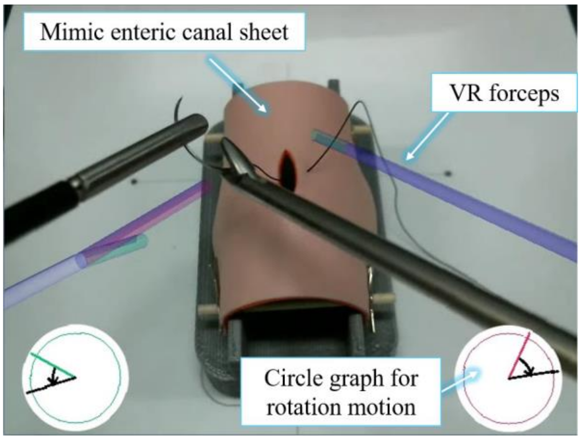


Fig. 6 Monitor image of training system

The system provides three types of training contents as followings; (i) viewing the movie of the supervised data, (ii) tracing the forceps operation of the supervised data without using forceps guidance function, and (iii) tracing the forceps operation of the supervised data by using forceps guidance function. In the training (ii), the effectiveness can be expected as well as the related work [4], where the repeated practice of forceps operation with viewing the movie of a skilled surgeon's forceps operation has a good influence on the learning curve of a trainee. Fig. 6 shows an image that a trainee views in a training. The virtual forceps are drawn on the movie of supervised data, that indicates the position of trainee' forceps. Finally, in the training menu (iii), the forceps control devices guide the trainee's forceps to correctly trace the forceps motion of the supervised data.

III. RESULTS

A. Preparation of supervised data

The authors chosen transfixion suture as the target surgical procedure for the system validation. The coauthor surgeon who is a certifying doctor of endoscopic surgery performed transfixion suture to a mimic enteric canal sheet. Then, the time-series data of three dimensional coordinates of the tip of forceps and the image of box inside were recorded as the supervised data. The supervised data need to include the essence of forceps operation that an advising doctor likes to teach, such as the curve of thread, the length of short tail, and the angle of needle, etc. By the way, the inessential motion, such as retaking the needle and reforming the shape of thread, should not be included in the supervised data. Therefore, the certifying doctor did transfixion suture over five times. About thirty minutes was needed to complete the supervised data.

Table 1 Results of questionnaires

A. Evaluation for Supervised Data	Score
1. Transfixion suture is effective for training	4.50(S.D. ±0.25, n=4)
2. Skill level of supervised data is effective for training	4.50(S.D. ±0.25, n=4)
B. Evaluation for Training System	
1. Ease of forceps operation	3.75(S.D. ±0.19 n=4)
2. Ease of opening and closing	3.75(S.D. ±0.19, n=4)
3. Weight of gear box and forceps control device	3.50(S.D. ±0.75, n=4)
4. Definition of the image of supervised data	3.75(S.D. ±0.19, n=4)
5. Visual field of the image of supervised data	3.50(S.D. ±0.75, n=4)
C. Evaluation for Display function	
1. The forceps drawn by VR can be recognized as own forceps	3.25(S.D. ±0.69, n=4)
2. Circle graph is effective to learn the rotation motion	3.50(S.D. ±1.25, n=4)
D. Evaluation for Guide Function	
1. Guide function for translation is available	4.50(S.D. ±0.25, n=4)
2. Guide function for rotation is available	4.25(S.D. ±0.19, n=4)
3. Guide function is effective for training	4.25(S.D. ±0.19, n=4)

B. Results of questionnaires

Before the experiment, this study explained the purpose and the contents of experiment to all test subjects. And this study gained the consent of participating to the experiment from all test subjects. Each test subject experienced three training menus and answered the questionnaires in respect to the specification and the function of the system.

Table 1 show the results of questionnaires, where the average score and standard deviation for each question were written. Each question was answered by five-grade evaluation.

The result of A-1 indicated transfixion suture is an adequate technique as the surgical procedure improving the operation skill of inexperienced doctors. Additionally, the result of A-2 confirmed that the supervised data of transfixion suture is effective for this experiment.

The results of B indicated that the forceps control devices and the gear boxes have little influence on the manipulation capability of the training system. And the visual information shown on the monitor was slightly wrong, because the specification of web camera was inferior than the endoscopic camera the test subjects commonly used in the operation room.
The results of C were significantly low. All test subjects were quite unused to virtual reality. Especially, virtual forceps were drawn on the image of supervised data, so they automatically recognize the forceps of supervised data as own forceps. And, the circle graph which showed the rotation angle of forceps was not helpful, since the test subjects already knew the importance of using rest in the procedure of transfixion suture. The authors considered that the circle graph would be effective in the training of inexperienced doctors.

The result of D indicated the guide function for not only translation but also rotation was highly appreciated. Especially, the guide function for rotational operation was effective because the rotary motion of right rest was necessary to correctly insert the needle to the sheet.

IV. DISCUSSIONS

The test subjects were the surgeons grew up through viewing the operations performed by their advising doctors. They had interested on the following functions of the training system; a trainee can practice the forceps operation with the same view point of an advising doctor, the guide function corrects the overs and shorts of forceps operation in training. Actually, these were the issues in the instruction of forceps operation. The authors considered that this system would improve the efficiency of not only training but also instructing. Additionally, they highly evaluated that the system enables a trainee to experience the level difference from the advising doctor and to intuitively find the motion necessary to perform a surgical procedure.

In this paper, the experiment was done by using one advising data in respect to transfixion suture, so that the trainee's level the system works effectively could not be obvious. For future, this study will add the patterns of advising data and conduct the experiments on the different level of surgeons.

V. CONCLUSIONS

This study aims to improve the training environment of endoscopic surgery in order to increase the number of the certifying doctor. The guide function of forceps operation is the advantage of the system, and it was highly evaluated by the surgeons. With the current advanced hardware and development in computer algorithms we can give our surgeons better tools to practice on . For future, this study likes to add the pattern of supervised data and the function which enables a trainee to adjust the strength of guide function according to his/her learning level. In addition, this study improves the system to make it possible to use a movie of actual surgery as a supervised data. The authors are expecting this function makes the system more practical.

VI. REFERENCES

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