Laparoscopic Surgery Simulator Using First Person View and Guidance Force

Kazuyoshi TAGAWA\textsuperscript{a,1}, Hiromi T. TANAKA\textsuperscript{a}, Yoshimasa KURUMI\textsuperscript{b}, Masaru KOMORI\textsuperscript{b} and Shigehiro MORIKAWA\textsuperscript{b}

\textsuperscript{a}Ritsumeikan University
\textsuperscript{b}Shiga University of Medical Science

Abstract. In general, minimally invasive surgery is seen as the most difficult surgery because there is limited field of view with an endoscope and force sensation from surgical instruments such as forceps is poor. Especially in early clinical education for medical students, a virtual reality surgical simulator would be an effective tool. In this paper, we propose a visuohaptic surgery training system for laparoscopical techniques. We recorded a video from a first person point of view of the instructor (expert). And we also recorded operation information (i.e. trajectory) of surgical instruments of the instructor. Then, we displayed the recorded video and the guidance force to trainees. We constructed a prototype surgery training system and the effectiveness of our approach was confirmed.

Keywords. Surgery Training, Laparoscopic Surgery Simulator, First Person View, Guidance Force

1. Introduction

Recently, laparoscopic surgery, also called minimally invasive surgery (MIS), has become a common surgical technique. There are a number of advantages (e.g. reduced hemorrhaging, smaller incision, less pain and shorter recovery time) to the patient with MIS versus an open procedure. However, advanced surgical techniques are required in MIS, because of the limited field of view with an endoscope and force sensation from surgical instruments such as forceps is poor.

In this paper, a novel VR training system for laparoscopic surgery techniques is proposed. In order to realize a multi-modal training system as if an instructor took a trainee's hands and taught, we propose a training system which presents the instructor's first person view and the guidance force to the trainee. Teaching laparoscopic techniques both visually and haptically is one of the advantages of a virtual reality (VR) surgical simulator. This is especially true in early clinical education for medical students; the simulator can be an effective tool. To confirm the effectiveness of our approach, we constructed a VR laparoscopic surgery training system, and verified the learning effect of the training system.

\textsuperscript{1}tagawa@tagawa.info
2. Methods

At first, we propose a visual instruction approach. As shown in Figure 1, our training system has two monitors. An upper monitor displays a laparoscopic image which is generated by the surgery simulation. In the laparoscopic surgery, information of the movement of the instructor’s hands and arms is important, because it provides information about how the movement of instructor’s instruments is generated. In our system, the lower monitor displays the instructor’s first person view. We recorded a video from the instructor’s first-person viewpoint which includes the movement of the instructor’s hands and instruments using a camera and then displayed it to the trainee from the same viewpoint.

![Figure 1. Overview of System.](image)

Next, we propose a force feedback approach as if the instructor is grasping the trainee’s hands. Ideally, the trainee would experience both the instructor’s instrument movements and the force applied by the instructor or deformable objects, but it is difficult to control both the position and the force at a haptic end effector without any control of the compliance of the user’s hand. In this research, we bind the trainee’s instrument position to that of an instructor’s instrument via a spring, according to

\[ F = K(P_{\text{instructor}} - P_{\text{trainee}}), \]  

where \( F \) is a force applied to the trainee’s instrument and \( P_{\text{instructor}} \) and \( P_{\text{trainee}} \) are the position of the instructor’s and trainee’s instrument.

Also note, in the laparoscopic surgery, instruments (e.g. forceps) are inserted through small incisions (holes) of the abdomen. In other words, surgeons manipulate these instruments with the holes functioning as fulcrums of levers. If the position of the tip of the instrument is determined, rotation (exclude axis along instrument’s shaft) of the instrument is also determined. In this research, we ignored this rotation (around axis along the instrument’s shaft) because of the limitation of degree of freedom of force presentation of our force feedback device. In our evaluation experiment, we chose a task which does not use this rotation.
3. Evaluation Experiment

To confirm the effectiveness of our proposed approach, we constructed a VR laparoscopic surgery training system in which our proposed approach was implemented, and performed an evaluation experiment. In this experiment, seven subjects (males, 22-25 years old, no impairment of vision, no knowledge about laparoscopic surgery, right-handers) participated.

As shown in Figure 1, our training system consists of a PC for simulation (CPU: Intel Core i7 920 2.67 [GHz], Memory: 12 [GB], GPU: ELSA Quadro 5000), two force feedback devices for force presentation (Sensable PHANToM omni), a USB camera for video recording (Microsoft LifeCam Cinema), a PC for video capture and presentation (Panasonic Let’s note CF-Y7), two monitors (24 [inch] LCD display).

We used a liver and a gall bladder model, Young’s modulus $E = 5.0 \times 10^{-1}$[kPa], density $\rho = 1.0 \times 10^3$[kg/m$^3$], initial number of nodes $n_{initial} = 572$, maximum number of the nodes $n_{maximum} = 2948$. A mass spring model was used for deformation simulation. To accelerate the deformation simulation, an online re-mesh deformation simulation and a parallel computing by a GPU [1] were used. A parameter $K$ of equation (1) was set to $1.0 \times 10^2$[N/m]. The guidance force was presented to the trainee through the force feedback devices.

At first, we recorded the laparoscopic surgery technique of the instructor (expert) using our simulator. Laparoscopic cholecystectomy was chosen as it was the most popular and fundamental laparoscopic surgery.

Procedure steps of the laparoscopic cholecystectomy are described as follows:

1. Grasp and pull up the gallbladder in order to able to see the whole gallbladder, cystic artery, and duct.
2. Ablate the gallbladder with a scalpel and forceps carefully.
3. Clips are then placed around the cystic artery and duct – two below and one above where they will be cut. Scissors are then used to cut the duct and artery.
4. The gall bladder is then dissected off the liver and a bag is used to remove it out of the abdomen.

As a task in this experiment, we chose the first step of this procedure, then we recorded the instructor’s manipulation parameters (temporal sequence of the position of the tip of the force feedback device, and opening and closing information of the handling of the surgical instruments), and video captured by the USB camera and the PC, during this step. Figure 2 shows examples of images of the laparoscope and the camera.

![Laparoscopy image](image1)

![USB camera image](image2)

*Figure 2. Example of images obtained by laparoscope and camera.*
Next, we performed following three experiments. We presented the instructor’s surgical technique through three different modalities:

- Experiment A: Laparoscopy image only,
- Experiment B: Laparoscopy image and USB camera image (instructor’s first person view), and
- Experiment C: Laparoscopy image, USB camera image (instructor’s first person view), and guidance force.

Between performing each experiment A, B, C, two or three day intervals were given to the trainees, in order to remove the memory of learning.

In each experiment, following four training steps were performed:
1. We asked each trainee to operate our surgical simulator freely for one minute to get used to operating the simulator,
2. Each trainee trained on the task five times continuously by using our training system,
3. Each trainee rested one minute,
4. Each trainee performed the task three times continuously without any guidance.

We measured the learning effect by comparing trajectories of surgical instruments.

4. Evaluation Result and Discussion

Table 1 and Table 2 show position error (distance between instructor’s and trainee’s position) at grasping point and position error at the end point, respectively.

As shown in Table 1 (position error at grasping point), in the case where comparing experimental result B and C with A, errors of subject 2, 4, 5, and 6 were improved, and also errors of subject 1 and 7 were slightly improved.

In Table 2 (position error at end point), in the case where comparing experimental result A with B, we could not find a difference. However, in the case where comparing experimental result A with C, errors of subject 1, 3, 6, and 7 were improved.

On the whole, improvement of position error the end point was smaller than the improvement of position error of the grasping point. Possible explanation for this result is that the surgical instrument’s numbers of movements and rotations at the position of the end point became large in comparison with at the position of the grasping point. In experiment B, trainees modify the motion of their hands and arms by comparing them with the laparoscopy image and USB camera image (first person view). However, this may be seen as difficult because the monitors are not stereoscopic and there are differences in physique between the trainee and the instructor. This problem will be solved by using stereoscopic video, or modification of the differences in physique using kinematic information acquired by a motion capture system (e.g. Microsoft Kinect).

### Table 1. Position error at grasping point [mm].

<table>
<thead>
<tr>
<th></th>
<th>Subject1</th>
<th>Subject2</th>
<th>Subject3</th>
<th>Subject4</th>
<th>Subject5</th>
<th>Subject6</th>
<th>Subject7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment A</td>
<td>11.1</td>
<td>32.6</td>
<td>7.6</td>
<td>44.8</td>
<td>45.4</td>
<td>81.5</td>
<td>13.5</td>
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<tr>
<td>Experiment B</td>
<td>4.6</td>
<td>12.5</td>
<td>13.6</td>
<td>22.0</td>
<td>15.4</td>
<td>1.2</td>
<td>6.4</td>
</tr>
<tr>
<td>Experiment C</td>
<td>2.8</td>
<td>13.5</td>
<td>8.1</td>
<td>22.5</td>
<td>22.8</td>
<td>4.6</td>
<td>7.1</td>
</tr>
</tbody>
</table>
Table 2. Position error at end point [mm].

<table>
<thead>
<tr>
<th>Subject</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subject1</td>
<td>Subject2</td>
<td>Subject3</td>
<td>Subject4</td>
<td>Subject5</td>
</tr>
<tr>
<td>Experiment A</td>
<td>88.9</td>
<td>50.8</td>
<td>116</td>
<td>17.4</td>
<td>25.3</td>
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<td>Experiment B</td>
<td>105</td>
<td>36.8</td>
<td>110</td>
<td>53.5</td>
<td>30.6</td>
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<td>Experiment C</td>
<td>50.5</td>
<td>58.1</td>
<td>72.9</td>
<td>27.4</td>
<td>35.9</td>
</tr>
</tbody>
</table>

Table 3 shows amount of time required in the task. In the case where comparing the experimental result of A with B; the required times of subject 2 and 4 were decreased; subject 7 were about to same; and subject 1, 3, 5, and 6 were increased. A possible explanation of this result is that the trainee modifies the motion of their hands and arms by using visual feedback only in experiment B, as a result, it took time to compare them with a monitor. This problem can be solved by using mixed reality technologies (e.g. head mounted display).

In contrast, in the case where comparing experimental result A with C, required times of all subjects were decreased. Therefore, our visuohaptic training system is more effective than conventional approaches.

Table 3. Amount of time required [s].

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<thead>
<tr>
<th>Subject</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Subject1</td>
<td>Subject2</td>
<td>Subject3</td>
<td>Subject4</td>
<td>Subject5</td>
</tr>
<tr>
<td>Experiment A</td>
<td>3.2</td>
<td>4.6</td>
<td>8.0</td>
<td>9.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Experiment B</td>
<td>4.9</td>
<td>2.6</td>
<td>9.8</td>
<td>7.0</td>
<td>5.1</td>
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<tr>
<td>Experiment C</td>
<td>2.4</td>
<td>3.0</td>
<td>6.7</td>
<td>5.7</td>
<td>3.9</td>
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</table>

5. Conclusions

In this paper, a novel visuohaptic training system for laparoscopic surgery technique using instructor’s first person view and guidance force was proposed. We performed an evaluation experiment, as a result, we verified the effectiveness of our proposed approach and found some issues in the approach.

Acknowledgements

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References