# Simulating Haptic Feedback of Abdomen Organs on Laparoscopic Surgery Tools

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**Abstract:** Minimally invasive surgeries (MIS) such as laparoscopic procedures are widely used for many types of abdomen surgeries because of its numerous advantages over open surgeries. They require very high levels of skills of surgeons acquired through experience. The best and the safest way of getting hands on experience is the computer simulation or virtual reality (VR). The VR surgical simulators have a great potential to revolutionize the training paradigm of surgical interns. The haptic feedback plays as equally as visual feedback to provide realistic environment to trainees. In this paper, we present a method incorporate hapitics on VR simulator. A software procedure is developed using the Libraries of Open Haptic Toolkit along with the Open GL graphic libraries to implement three basic haptic ranges: soft, mild(firm) and hard into organ models. The feedback of the expert surgeons in the field was obtained to model the organs rather than measuring mechanical properties of soft tissues due to practical limitations. A commercially available six Degrees of Freedom (DoF) position sensing and three DoF force feedback haptic device is used to implement the interface.

**Key words:** Force feedback, haptic, laparoscopic surgeries, virtual reality.

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## 1. Introduction

Minimally Invasive Surgeries are considered today to be a better way of performing many abdomen surgeries due to its a variety of benefits such as short hospital stays, fast recovery time, less post operative care, fewer complications and a low rate of infections over open surgeries [1]. Although patients are benefitted from this new technology, during laparoscopic procedures surgeons have several challenges like loss of depth perception of the images of organs in the area of interest produced by the endoscopic camera, the fulcrum effect and the reduced haptic feedback for tool-tissue interaction. The indirect visualization and indirect manipulation of tools disturb the hand-eye coordination of the user [1], [2]. Complexities due to lack of experience sometimes force surgeons to convert the laparoscopic procedure to conventional surgeries mainly. Therefore, a proper training is essential for surgical interns before assisting in the actual surgeries [3], [4].

## 2. Previous Related Work

The available training methods for laparoscopic surgeries are categorized as box trainers [5], Virtual Reality (VR) simulators [5]-[7] and Augmented Reality (AR) surgical simulators [5], [8], [9]. The box trainers are equipped with physical models such as synthetic or fabric material or cadavers [10]. Since the system uses real laparoscopic instruments to interact with organ models, the trainee will experience the interaction forces through the tool handle while training. However, this feedback is different from the natural feedback provided by live surgeries. On the other hand, this system does not provide objective evaluation which is essential to evaluate trainee's skills before transferring to operating room. Organ models need frequent replacement and thus quite expensive, and therefore, box trainers are not widely available in the healthcare system around the world.

The general consensus is that VR simulators provide an immediate solution for laparoscopic surgery [9] training over traditional box trainers [10]. VR simulators provide objective evaluation of trainee performance but most of the simulators lack the feeling of tool- tissue interaction forces as provided in box trainers with physical objects. Majority of work carried out has emphasized that well designed computer simulation system enables the trainee surgeon to improve and enhance psychomotor skills for laparoscopic surgeries. In most VR simulators, haptic solutions are far behind compared to visualization because of the complexity of the procedures [5]. Many researchers have reported that haptic feedback is essential for VR simulators to improve the fidelity of the simulator [1], [2], [7], [9], [11], [12].

Augmented Reality (AR) is an advanced training paradigm of VR simulators. The AR combines the virtual reality with the physical world [5]. AR simulators provide the objective assessment of trainee performance as VR simulators in addition to the haptic feedback provided by box trainers [5]. Even though, the realistic haptic feedback is fundamental to the VR simulator, majority of researchers have concluded that it would be a very critical task [1], [12] as haptic needs simultaneous input/output mechanism which involves a large number of touch receptors [13], [14]. It has been found that the required haptic update rate for realistic haptic feedback to be at least 1000Hz [15]. However this is highly challenging compared to visual refresh rate which is about 30Hz [13], [16]. Other key factor is the availability of proper organ force models. As the mechanical properties of biological tissues are very complex [1], [2], [7], [15], [16] and ethical issues are involved, the development of deformable organ models is rather critical. Therefore, overcoming this lack of facility in VR simulators is highly challenging active research area for medical simulators.

There are numerous VR simulators currently available for MIS training [7], [13]. Each simulator consists with different training modules for trainees to learn many basic skills of laparoscopic procedures such as cholecystectomy and gynecology [13]. None of the VR simulators equipped with proper organ models and they do not provide enough feedback for tool-tissue interaction as experienced in actual surgeries [13]. Therefore, the existing training methods do not fulfill trainee requirement [7], [12].

The organ models are a core component of a VR training simulator to display accurate displacement for pulling and pushing forces [17]. Incorporating real force properties on VR organ models is very difficult problem faced by many researchers around the world [6], [8], [12]. In this paper, we propose a novel approach to incorporate haptics to virtual organ models to simulate laparoscopic surgery tool interaction with tissues. As an initial step of the procedure, we implemented three basic force ranges: soft, mild, and hard force feedback through tool handles on abdomen organ models. We believe that, the simulated organ models can provide an interactive training environment for trainee surgeons.

## 3. Methodology

VR simulators have been developed for a wide range of procedures to find solutions for the difficulty in haptic perception during training. The development of proper organ models is the highly challenging task in this procedure [6], [12], [16]. Researchers have used CT (Computed Tomography), MRI (Magnetic Resonance Imaging) of Visible Human data set of abdomen (VHP abdomen) [18] to develop virtual models of anatomical organs [2], [8], [19]. In this study, we used the color Cryosection data set of Visible Human Project of the National Library of Medicine, USA to generate virtual models of abdomen organs due to its image quality and high resolution over CT and MRI data [2]. In the first phase of this project, virtual models of five abdomen organs such as liver, gallbladder, bowel, stomach and skin were developed using VTK and ITK open source software [17]. Fig.1 shows the organ moles developed using color cryosection data of the Visible Human Project of the National Library of Medicine. Kinesthetic feedback plays a major role in laparoscopic surgeries and it is extremely difficult to gain a proper training without this feedback. Therefore, the hardware interface system must be capable of providing interaction forces along with the correct position and orientation: roll, pitch and yaw of the tool-tip. Furthermore, the system needs high precision simultaneous input output mechanism to provide the feeling of real-life surgery.

### 3.1. Previous Implementation

In this section we summarize on our previous work on developing a hardware interface to incorporate haptics into a laparoscopic surgical simulator [17]. The system incorporated with two optical incremental encoders to measure 2-DoF (yaw and pitch). An optical displacement sensor and a high resolution potentiometer were used for the measurement of the other two DoF (roll and insertion). The system was capable to provide spatial location information of the tool tip in the work space in addition to the force feedback feeling in all three axes for tool-tissue interaction up to some extent. Even though, the system is a low cost and less precise method, it can provide high resolution at an acceptable price. Fig.2 shows the mechanical model of hardware interface designed to the VR simulator.

The movement of the laparoscopic tool is mapped with the virtual interface. Therefore, the physical tool tip position of the laparoscopic tool will be the same as the tool position in the virtual environment. However, there were many challenges in designing the hardware interface which gives four DoF. The system requires light weight, durability and resistance to the deformation. Aluminum is lightweight and durable but the resistance to deformation was not adequate. Therefore, the different parts of the system were designed with aluminum together with nylon. The shaft which connected to encoders undergoes deformation that was very difficult to avoid. This leads to incorrect readings in the encoder. The braking system consists with an electromagnet which can activate accordingly when the tool tip touches with the organ models in the virtual environment. The braking system constraints the tool movement when it collides with virtual organ models. The virtual environment calculates the forces needed for haptic feedback and transmits to the braking system.

The amount of braking force depends on the type: soft, firm (mild) or hard of the virtual organ models. For instance, less braking force is required to identify soft tissues compared to hard tissues. Because of light weight and smaller in size, braking can be controlled by the induced current to the system.

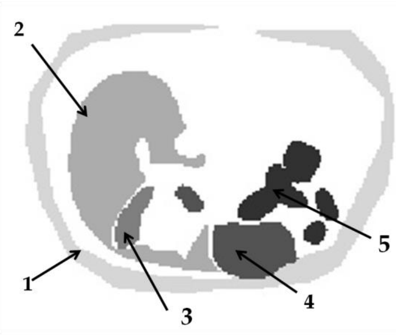

Fig. 1. Axial view of abdomen organ models: 1: skin, 2: liver, 3: gallbladder, 4: stomach, 5: bowels.

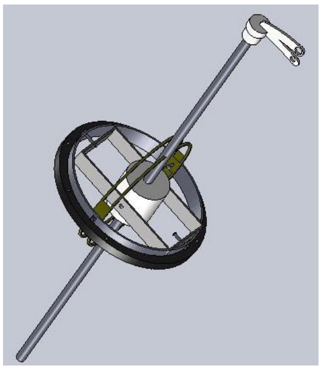

Fig. 2. Design of the mechanical model of hardware interface.

### 3.2. Proposed Implementation

Due to the delay in the braking system and limitations of accuracy, the previous system did not meet the user experience for force feedback up to the required level. Because of these drawbacks and limitations, our next approach is to develop the hardware interface through which the surgical residents can gain skills in a very realistic manner.

Very precise haptic devices are commercially available today and they vary greatly in the degrees of freedom they offer, the force and torque they can apply, the size of their workspace, the shape of the end effectors and probably, in price [13]. To feel both forces as well as torques, it requires six degrees of force feedback but typically this is not easy to provide due to many technical difficulties. In our study, we have selected the Phantom Omni haptic device [20] to provide six-Degrees of Freedom positional sensing along X, Y and Z axis together with the tool orientation (roll, pitch and yaw) in work space. In addition to this positional sensing of the laparoscopic tool, the device provides three DoF force feedback to the simulator.

To reflect actual feedback for tool tissue interaction, the organ models should contain the actual tissue properties. However, developing organ models with actual tissue properties is a rather complex issue and thus very little work is carried out to incorporate real organ properties [16]. Therefore, we introduce a novel method to implement force feedback for interaction forces. A software procedure is developed using the Libraries of Open Haptic Toolkit along with the Open GL graphic libraries to implement three basic haptic ranges: soft, mild/firm and hard into organ models. The proposed method allows the user to change the tissue properties such as, damping constant, stiffness and friction of organ models. The user can feel the interaction of virtual tools with the said organ models while taking tool navigation information from the same tool. The proposed VR interface can differentiate the organ models initially into three force ranges: soft, mild/firm and hard and the user can experience the force feedback through the haptic interface for the laparoscopic tool as shown in Fig. 3.

Soft tissues are very complex and their mechanical properties are not properly known. We hypothesis that if the organ models are developed with different normalized stiffness values, then they could provide natural feeling to the user. The stiffness is normalized by the device maximum stiffness value, which is 2.31 N/mm the selected device. For this research, we obtained the feedback of the experts in the field. They interacted with the virtual organ models through the haptic interface by changing the stiffness of tissues. The feedback for tool tissue interaction with organ models was collected by changing the normalized stiffness of organ models. We used this data to average normalized stiffness values of the organs in three categories representing soft, mild and hard properties. We then used the calculated normalized stiffness values to implement haptic properties of virtual organ models.

## 4. Results

The feedback was obtained three times from expert surgeons and twice from senior registrars and registrars for each organ model. The feedback obtained from registrars spread over a large range and therefore, variation is relatively large compared to surgeons. Therefore, we did not use the feedback obtained from registrars and considered only the feedback of expert surgeons to implement soft, mild and hard force ranges to the virtual organs. Fig. 4 shows the combined data obtained from experienced surgeons.

The normalized stiffness of liver is quite high compared to other organs as shown in Fig. 4. The liver is considered to be a firm (mild) organ and the other four organs: gallbladder, stomach, bowels and vessels are considered as relatively soft organs. Thus to determine soft and firm force ranges, the average values are considered. Table 1 summarizes the average normalized stiffness for each organ with their standard deviation.

Fig. 3. Hardware interface to the proposed VR Simulator.

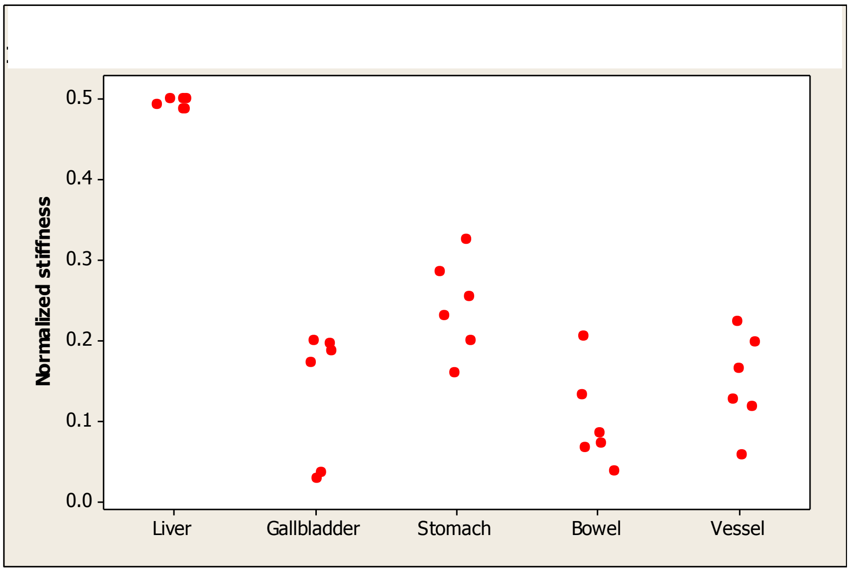

Fig. 4. Individual stiffness value plot of liver, gallbladder, stomach, bowels and vessel feedback for all tries of expert surgeons.

Table 1. Average Normalized Stiffness Values of Organs with Their Standard Deviation

| Organ | Mean | Std. deviation |
|---|---|---|
| liver | 0.49 | 0.01 |
| gallbladder | 0.14 | 0.08 |
| stomach | 0.24 | 0.06 |
| bowel | 0.10 | 0.06 |
| vessel | 0.15 | 0.06 |

To determine a fair normalized stiffness value for soft feeling, the average of mean values of each soft organ shown in Table 1. is considered. Accordingly, we estimated the most appropriate normalized stiffness to provide soft and mild/firm feelings to the user. Table 2 summarizes the calculated normalized stiffness and estimated stiffness values that we can assign to simulate soft and mild/firm feelings. By considering the difference of the normalized stiffness vales corresponding to soft and mild feelings along with our experience, we propose a normalized stiffness value of 0.83 to the simulator to experience the hard feeling.

We conducted experiments for evaluating the experience of soft, mild/firm and hard force ranges of the organ models. As an initial step of evaluation of the simulator, we have used three identical cubes with soft, firm and hard force ranges. In the testing procedure, ten identical cubes with different force ranges are randomly generated and the trainee has to touch the organ models and determine whether the model is soft, firm or hard. We have done the preliminary evaluation with a non specialized group. For that we have selected ten research students in our biomedical laboratory and conducted the procedure as follows. In the first round, the trainees were given a good training through which they studied three force ranges properly. Immediately after the training, the Test 1 is carried out. The second round was started at least two hours later from the first test for the same group. Test 2 was performed without any training, only with their past experience. Immediately after the Test 2, Test 3 is carried out after giving an another training session. Results obtained from each trainee are tabulated in Table 3.

Table 2. Estimated Stiffness Values for Three Basic Haptic Properties of Tissues

| Tissue property | Normalized stiffness | Estimated stiffness N/mm |
|---|---|---|
| soft | 0.16 | 0.37 |
| mild/firm | 0.49 | 1.13 |
| hard | 0.83 | 1.92 |

Table 3. Percentage of Accuracy of Ten Participants of Identifying Soft, Firm/Mild and Hard Organ Property

| Participant<br>Test round | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Average with standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| First round | Test 1 | 90.0 | 70.0 | 90.0 | 70.0 | 70.0 | 70.0 | 70.0 | 100.0 | 80.0 | 40.0 | 75.0±16.5 |
| Second round | Test 2 | 90.0 | 90.0 | 80.0 | 80.0 | 100.0 | 70.0 | 70.0 | 80.0 | 70.0 | 60.0 | 79.0±11.4 |
| | Test 3 | 100.0 | 100.0 | 100.0 | 80.0 | 90.0 | 100.0 | 70.0 | 100.0 | 90.0 | 90.0 | 92.0± 9.8 |

According to results in Table 3, the average accuracy of selecting correct organ models increases with the increase of training sessions and the standard deviation is decreased. Therefore, our simulator supports trainee students to categorize organ models basically into soft, firm/mild and hard. Table 4 summarizes the probability of selecting correct organ property in each test. According to the results in Table 4, with the training sessions, probability of selecting a soft model is highly accurate compared to other two types.

Table 4. Probability of Identifying Correct Organ Property

| Organ property | Test1 | Test2 | Test3 |
|---|---|---|---|
| soft | 0.92 | 1.00 | 1.00 |
| mild/ firm | 0.65 | 0.75 | 0.89 |
| hard | 0.63 | 0.63 | 0.88 |

## 5. Conclusion and Future Directions

We have proposed a novel method to simulate haptic feedback of abdomen organ models for tool tissue perception using a commercial haptic device. The organ models were generated in the three basic force ranges soft, mild and hard which considered being the minimum requirement. The process mainly involved in collecting force data directly from the experienced surgeons for estimating feedback forces. The simulated organ models are capable of providing force feedback in all three dimensions. The generated organ models could enhance the existing VR laparoscopic training systems by incorporating natural feelings through the tool handles. The system is mainly developed with the open source software with a Phantom Omni haptic device.

The mechanical behavior of biological tissues is extremely complex and viscoelastic. Soft tissues exhibit nonhomogeneous, anisotropic and nonlinear behavior [15], [16]. Properties also change with the age and sex. Furthermore, properties change with the in vivo and ex vivo state of measurements. High computational power and fast haptic update rate are also key issues for this kind of simulation [13], [16]. Therefore, majority of researchers have mentioned the difficulty of developing a real time simulator for laparoscopic surgery training. Very little work is done on real organ force models. Thus, we have followed a new approach to integrate force feedback into organ models. We have developed a software procedure which can support to change the normalized stiffness of organ models. The force feedback experienced for tool tissue interaction in actual surgeries was obtained with the support of experienced surgeons. The surgeons who involved in this study have surgical experience of above seven years and gave us very good feedback to develop reasonably accurate organ models in the simulator.

We are in the process of assessing the precision of the simulated organ models with experts in the field. In future, we hope to improve the organ models by simulating deformation and grasping forces.

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