

A Novel laparoscopic surgery simulator: System and Evaluation

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Abstract— a full-fledged surgery simulator should provide functions which really train and improve surgeons' skill. In this work, we comprehensively illustrate our surgery simulation system from its function, architecture and methods. Next, we evaluated our system from the doctors' perspective. Surveys are carried out to investigate doctors' experience of the system. Experiments are conducted to record their skill improvement during a certain period of time of training using our system. From the evaluation, some valuable points were concluded for future research direction.

Keywords: Laparoscopic, Virtual Surgery, training, evaluation

I. INTRODUCTION

NOWADAYS, with the development of the computer technologies, the surgery training can be performed on the computer with the haptic devices. The potential benefits of realistic Virtual surgery are extensive: cut in cost, objective assessment of surgical skill, decreased risk to patients as surgeon's progress along.

Other than the system performance and stability, a full-fledged surgery simulator should provide functions which really train and improve surgeons' skill [1]. This should be the doctors' evaluation and the assessment of the improvement of surgeons' skills. Yet, till now, abundant tests have been done by researchers and developers to evaluate the efficiency, accuracy or robustness of the system, evaluations from the real users, the doctors', is still few. Moreover, the methodologies of the evaluation are also worthwhile to be studied.

Our Minimal Invasive Surgery (MIS) system covers the main functions of a laparoscopic surgery simulation system including organ modeling, visual rendering and haptic rendering in a versatile application. Several specific operations like depth training and cutting are devised for

doctors' skill training. MIS employs some novel algorithms to high efficiency and robust simulation which will be introduced in section 2. Furthermore, to evaluation our system, a set of methodologies has been proposed from the doctors' perspective. Some valuable points for further research direction were already concluded from the initial results.

The paper is organized as follows; section 2 covers the over-view of functions, the system architecture and the main methods used to devise the functions. In section 3, methods used to evaluate our system are described, oriented to evaluate our system from the doctors' perspective. Section 4 shows the result of the evaluation. Section 5 is the conclusion.

II. SYSTEM AND METHODS OVERVIEW

A. Overview of Functions

Our laparoscopic surgery simulator enables four main functions currently:

- (1) *Modeling and Visual Rendering of the patient's organs under the laparoscopic*
- (2) *Haptic rendering of the tissue's characteristics by soft-tissue modeling and haptic devices.*
- (3) *Depth training and*
- (4) *Cutting training.*

We will introduce the 4 main functions one by one. First, we have a look at the overview of the system. As depicted in Fig.1, the surgery training platform consists of two views; one is the global view while the other is the laparoscopic view. Two views are switchable. The trainees can freely move the laparoscopic for areas of interest.

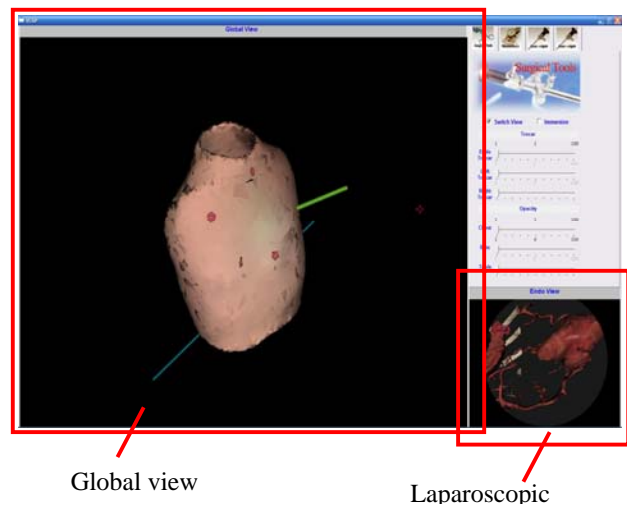


Fig.1 The surgery training platform screen shot

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Skin and ribs are rendered for realism enhancement while they can also be set to transparent or hidden. The virtual organs are modeled inside the thoracic and abdominal cavity and are rendered exactly corresponding to the patient's since they are modeled from the CT scanned data of the patient and further rendered. The surgery trainees could scale and observe the simulated patient's organs from different angles thereby.

As many doctors from the Renji Hospitals claims, one of the biggest difficulties in laparoscopic surgeries is the lack of depth awareness. When conducting surgery by watching the flat 2D screen, it is hard to judge the depth between the tool and the target organ. Therefore, we designed a depth training module, which is specifically oriented to train the feeling depth.

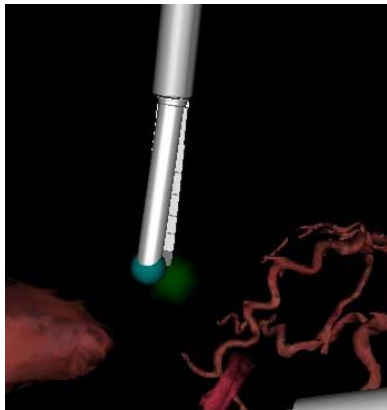


Fig.2 The depth training screen shot

As shown in Fig.2. The task of the depth training is to clip the small blue ball, transfer it and put it into the target green box through the IMMERSION tool. The start position of the small blue ball and the relative distance both can be set manually by the user.

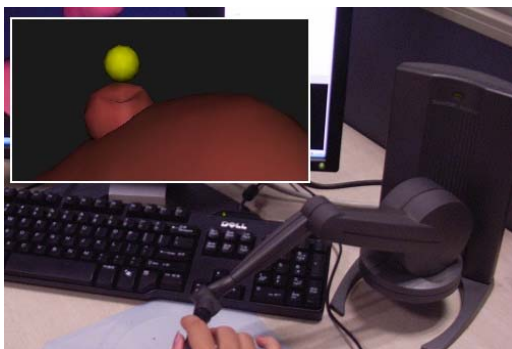


Fig.3. Haptic rendering of the organ.

The surgery training system also enables haptic rendering, which enables the surgery trainee to feel the characteristics of the organ.

If parameters are set correctly, the physical characteristics also precisely match the patients. With the haptic device

PHANTOM, the surgery training could 'touch and feel' the physical character of the soft tissue or rigid bones inside the body. Therefore, the parameter setting and validation work need to be more emphasized in the future.

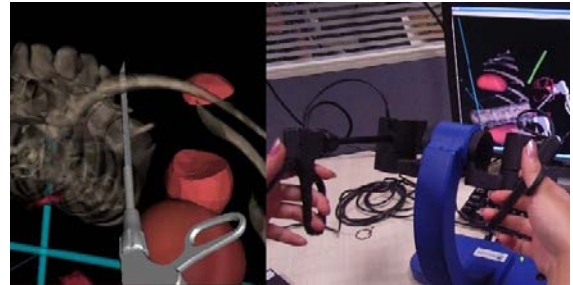


Fig.4. Cutting training

Last, our surgery simulator enables cutting under laparoscopic. As shown in Fig.4, the surgery trainee can repetitively train dissecting a target object with the IMMERSION tools.

B. System Architecture

The architecture of our surgery simulation system is deployed as in Fig.1. It contains four major parts: a data processing unit (Fig.1.a) which converts the DICOM (Digital Imaging and Communications in Medicine) image data into a volume mesh; a set of methods to model the surgery (Fig.1.b), a user interface façade part (Fig.1.c) which interacts with the devices (Fig.1.d, e and f).

The data processing unit performs two steps, smoothing and meshing, to convert the original DICOM data to volume mesh.

The component of virtual surgery methods (Fig.5.b) is the core of our system. "Observer" pattern [2] is employed in the design of the architecture. Methods of different functions are wrapped into a set of low-coupled modules. We have soft-tissue-modeling, collision detection, collision response, cutting and clipping modules currently. They provide surface to interact with a 'whiteboard', which contains the global information of the system like the organ mesh or the device status. The surgery method modules work as the observer of the whiteboard. If the whiteboard's status changes, the whiteboard notifies its observers to take corresponding actions. For instance, if the topology of the organ mesh is changed, the "whiteboard" will notify the soft-tissue-modeling module to rebuild the model. This structure is clear to read and easy to scale when another function is added.

The user interface contains a monitor to render the 3D objects (Fig.5.d), a force feedback device (Fig.5.e), 'PHANTOM desktop', which is provided by the company "SensAble Technologies", and a "Virtual laparoscopic" interface device (Fig.5.f) provided by the 'IMMERSION' cooperation.

C. Methods overview

In this sub-section, we will briefly describe the methods used in the surgery simulation system according to the modules in Fig.5:

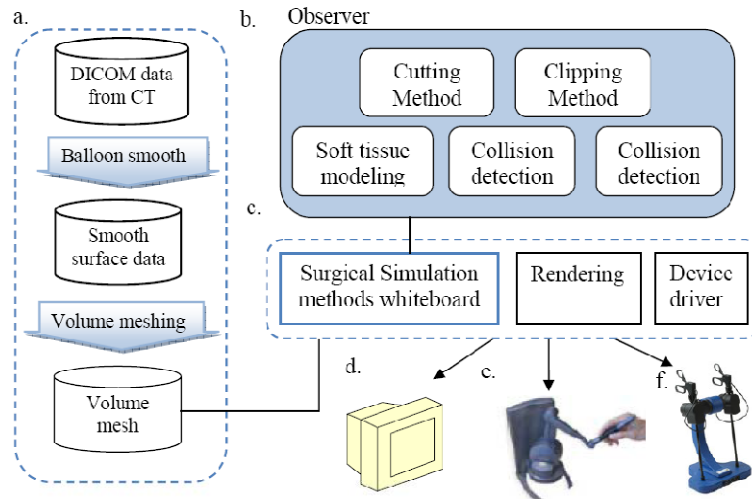


Fig. 5. The architecture of the system

(1) Data Processing Unit

Volume mesh is used for model representation in MIS. Surface mesh of the organ is got by matching cube [3] on the CT scan data. To construct the volume mesh from the surface mesh, an optimal spatial-decomposing meshing algorithm [4] is devised to generate a high-quality volume mesh.

(2) Soft-tissue modeling unit

We employ a constraint particle system [5] which has length, surface and volume constraints. Constraint particle system is robust in simulation while efficient in computation, though it has a draw back in accuracy compare to FEM. That will be improved in the future

(3) Collision Detection unit

An optimized hierarchical spatial hashing method [6] is employed for collision detection. Compared to the early spatial hashing using uniform grid cells [7], our collision detection method employs a dynamic hierarchical spatial partitioning mechanism which adaptively adjust the size of the grid cell according to the object size [8], therefore highly increase efficiency.

(4) Collision Response Unit

A hybrid collision response method [9] is devised for rapid generation of reasonable deformation and continuous force feedback. It uses the penetration depth method [10] for feedback force generation which keep precise contact surface using the contact surface method [11].

(5) Cutting Unit

A novel hybrid cutting method [12] is employed in simulating cutting operation. This hybrid cutting method combines progressive and non-progressive cutting. Progressive cutting [13] is applied on the outer hull of the target organ to keep visual reality while non-progressive cutting [14] is applied to in the inner core of the organ to keep efficiency and stability of simulation.

III. EVALUATION METHODS

To evaluate our system, we invited 20 doctors from the cooperate hospital, Renji Hospital. Among them, 5 are experienced (work experience > 10 years), 10 are less

experienced (work experience <10 years) and 5 are intern doctors. The portion is chosen according the approximate real distribution of differently experienced doctors in the hospital.

A lot of experiments about efficiency and stability of our system have been done by researchers and developers [8, 9, 12], but it is more important to evaluate the system from the doctors' view, since they are the end user of the surgery training system

We invited them to use our system and fill out the survey. The survey is most related to efficiency and stability by tens of very detailed questions. It also includes the doctors' own sense of skill improvement.

We also record and evaluate the doctors' improvement

TABLE I
SUMMARIZATION OF SURVEY BY THE SURGERY TRAINEES

Criteria	Feedback	Ratio
User interface:	Easy to use	83%
Easy to use and control through key board , mouse, PHANTOM and IMMERSION tools	Fair to use after guidance	15%
	Difficult to use	2%
Visual reality:	Good virtual reality	65%
Organs, tools are placed correctly and simulated really	Modest virtual reality	30%
	Poor virtual reality	5%
Haptic reality:	Good haptic reality	44%
The soft-issue deforms realistically and force feedback is continues and realistic	Modest haptic reality	50%
	Poor haptic reality	6%
Efficiency :	Efficient	87%
Operations are fluent without lag-behind	Modest	13%
	Poor efficiency	0%
Depth training:	helpful	92%
Dose the depth training helps in improving the doctors' perception of depth	It has some use	8%
	It has little use	0%
Cutting training:	Helpful	73%
Does the cutting training helps in improving the skill in remove a certain object by the cutting tool under the laparoscopic	It has some use	22%
	It has little use	5%

after training by the system. The system and devices have been placed in the hospital for 2 weeks, 10 work-days in total. We required the doctors who participated in this experiment to conduct depth training 20 times and cutting training 10 times a day. We recorded the mean time they completed a transferring task every day and the rate they successfully remove a target object, for instance, a tumor on the kidney, by the cutting tool during a certain time.

IV. RESULTS

We summarized the result of the survey to Table1. The ratios are calculated by the of answers to several questions related to the function, like system, visual reality and so on.

From the result of the survey, we get that the user interfaces, the visual reality and the efficiency of our system perform fair while the Haptic reality doesn't yield a desirable outcome. It shows that doctors are far more sensitive to haptic rendering than developers are. Therefore, further research on parameter determination for soft-tissue model and collision response need to be emphasized.

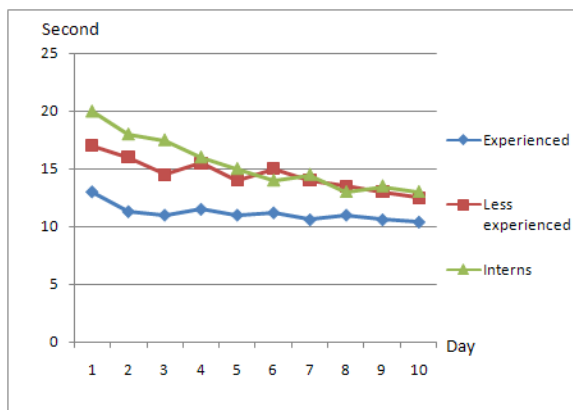


Fig.6. The average time surgery trainees complete a depth training task during ten days.

Fig.6 records the change of average time the doctors took to complete a depth training task during two weeks, 10 work days in total. As the chart illustrates, the mean time to complete a task for the experienced, less experienced, and intern doctors have all decreased. Especially for interns, the increase in their speed to complete a task is most significant, while the improvement of experienced doctors is not so evident. This is probably because experienced doctors have already been professional in controlling the surgery tools and manipulating the organs under laparoscopic. Therefore, the slight increase may be the evidence of their familiarity with our system.

V. CONCLUSION

In this paper, we fully described our system by overview of functions, system architecture and methods step by step. Then methods to evaluate the virtual surgery training system from the doctors' perspective are proposed. Some initial results are also given in the results section. Some important points are

already got from the current results of the evaluation. For instance, from the result we get that the doctors are far more sensitive on haptic rendering than developers are. Therefore, the research on parameter determination on soft-tissue need to be more emphasized in the future research.

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