A PC-based Laparoscopic Surgery Skills Training and Assessment System

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Abstract—**The purpose of this study is to build a cost-effective and easy-to-popularize laparoscopic training system based on improving traditional training box. The system has the capability of objective skills assessment and the function of automatic recording of training process and results, as well as 3-dimensional coordinate tracking of instruments. The results of pilot experiment in laparoscopic-assisted grip skill assessment had been shown the system can assess the different grip ability level between the senior surgeons and junior residents. Regarding to the evaluation of training effectiveness, five subjects without laparoscopic surgery experiences were asked to perform grip training for five days to observe their training curves. According to the experimental results, the total time taken for subject 1 to subject 5 are improved by 54.9%, 52.0%, 60.6%, 23.3%, and 63.5% separately.**

I. Introduction

The minimally invasive surgery (MIS) is a mainstream of global surgical development, which has also been widely used in a variety of surgical procedures. For MIS, laparoscopic surgery is one of the earliest developing domains and also the most mature one. Using several small incisions on patient's abdomen and performing surgery with the aid of a camera, trauma is obviously reduced and postoperative recovery of patient is faster than traditional surgery. However, laparoscopic surgery has a major challenge for the training of surgeons, not only the lengthy training time, but also the steep learning curve. The technical challenge for surgeons includes but not limited to fulcrum effect, limited depth perception, long instruments amplify movements, dampen tactile feedback, and hand–eye coordination.

In clinical practice, the generally training of surgeons in MIS adopts the following ways. 1) A simple training box is used for some basic surgical skills exercise, such as grip and moving objects. However, this simple surgical training box cannot provide the objective assessment. 2) The animal experiments, pigs are usually used for the actual surgical simulation. This approach can approximate to the experience of real surgery. However, due to the high cost of animal experiments and thus such training is more suitable for experienced surgeon to learn a new method of laparoscopic surgery. The junior surgeons usually cannot receive the laparoscopic animal experiments if they without some basic skills. 3) On-site learning, general beginners served as an assistant and slowly familiar with the steps of the laparoscopic surgery. However, due to the lengthy study time and steep learning curve, it requires at least more than one or two years of training for basic laparoscopic surgeries, such as laparoscopic-assisted appendectomy, or cholecystectomy.

To solve above problems, multiple laparoscopic surgery simulation training systems have been developed to train laparoscopic skills, which can effectively reduce the trainees' learning time and learning curve for laparoscopic surgery before entering the operating room [1]-[4]. The laparoscopic surgery simulation training systems could be divided into three categories: traditional box trainers, visual reality (VR) simulators [5]-[8], and augmented reality (AR) simulators or hybrid simulators [9]. Different types of training systems have their pros and cons. The advantages of traditional box trainers are realistic haptic feedback and cost-effective. On the other hand, the subjective assessment and lack of interactivity are its disadvantages. In opposition to box trainers, VR simulators provide objective assessment of performance and interactivity, but its weak points are lack of realistic haptic feedback and assessment protocol. As for the AR simulators, it is considered that the realistic haptic feedback, objective assessment of performance and interactivity are the pros. Nevertheless, the assessment protocol still needs to be developed [10].

Because of the commercial laparoscopic surgery simulation systems are quite expensive [11], few hospitals could afford such a system. It still would not be universal for surgeons learning to use, even if they have such system. The traditional training box is cost-effective and offers a physically realistic environment which is based on real instruments interacting with objects. As a result, this study introduced an improvement of traditional training box which provides the objective skills assessment, and it also can automatically record the training process and results as well as track 3-dimensional (3D) coordinates of instruments for visual assist. This combination of the advantages for box trainers and VR simulators could be not only cost-effective but also easy-to-popularize.

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II. METHODS

A. System Architecture

In this study, we developed a PC-based training and skills assessment system (BESTtrainer I) for junior residents to increase their basic laparoscopic surgery skills. The infrastructure of system is built for developing physical and VR training and skills assessment modules together. The system architecture could be separated into two main parts, a training box and a PC with custom software. Fig. 1 shows the architecture of system. The training box includes image capture modules, replaceable physical training modules, and 3D coordinates acquirement module. This system provides two image capture modules, a low-cost webcam (640 × 480 pixels, 30 fps) and a real endoscope for user to observe and record the inside image of training box. The communication interface between the webcam and PC is a standard USB interface. However, the output signal of the endoscope is an analog NTSC signal (720 × 480 pixels, 30 fps) which is captured by a video capture card on PC.

The system also provides two physical training modules, grip and stability training modules. Every module is embedded an 8-bit microcontroller (MCU) PIC18F2520 and provides a definition hardware interface to connect with training box, which is communicating with PC via the UART. The baud rate is set as 9600 bps. Moreover, the physical modules provide a convenient way to replace different training module if users want to change it. Besides, there is a Minoru 3D webcam (800 × 600 pixels, 30 fps) be used for tracking the tip of instruments. The communication interface between the 3D webcam and PC is also a standard USB interface.

On the PC, we developed a client software runs on a window XP-based PC (2.66 GHz Quad CPU, 4 GB RAM, 500 GB HD), includes a user interface and an image recognition unit which could capture 3D coordinates of surgery instruments (such as laparoscopic grasper, laparoscopic scissors) in order to develop 3D visual assist and stability evaluation of hands' movement. The main functions of the user interface include the webcam or endoscopic image display and recording, the 3D visual assist systems, the training results and consuming time display, as well as database query system.

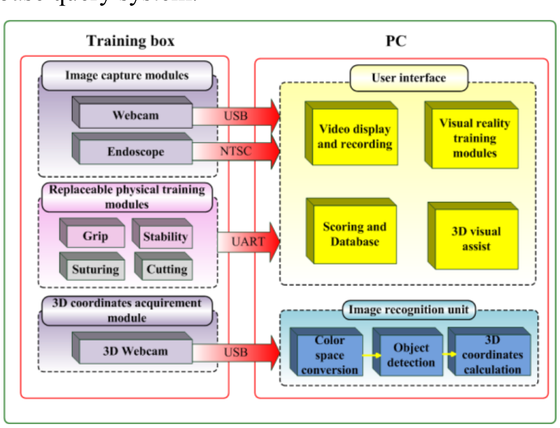


Figure 1. System architecture.

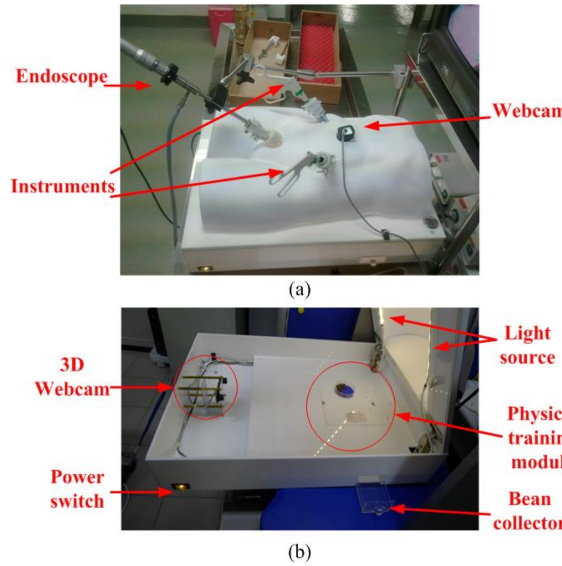


Figure 2. Layout of the training box. Fig. 2(a) shows the outside of the training box and the Fig. 2(b) demonstrates the inside of the training box. There are two line-type white LED light sources, one 3D webcam, one grip training module, and one bean collector.

B. Physical Training Modules

There are two physical training modules, grip training module and stability training module, allow users to practice their hands' stability and operating skills of instruments. Grip training module mainly focuses on training the user's grip and transfer skills, and the coordination between both hands.

There are two steps that users have to complete in grip training module. First, trainee should clip a bean from container and lift the cover which is above the target hole. Second step is putting the bean into the hole. The operating image is shown in Fig. 3(a). The diameter of bean is about 7 mm, and the diameter of the hole is 8 mm. A slotted optical sensor (MOC70T4) is used to detect if the bean pass through the hole. The MOC70T4 consists of an infrared emitting diode facing a phototransistor in a molded plastic housing. A slot in the housing between the emitting diode and the detector provides the means for mechanically interrupting the infrared beam. In the beginning, there are ten beans on the container. The less total time taken to finish is better result in the grip skills.

The stability training module is addressed to increase the trainee's stability of hands. In this training, the user needs to move the instrument such as grasper to cross the two sensors without touch collision sensor. If the instrument touches the collision sensor the training system will record it. Of course, the less total time taken and less number of collisions are the better result in the stability. As Fig. 3(b), sensor 1 and sensor 2 are slotted optical sensors which are the same in grip module. The principle is that the tip of grasper is connected to ground and when the tip touch the collision sensor would cause an interrupt signal for MCU to record the touching. The width of pathway could be any distance for different instruments. In this study, it is 8 mm for the grasper.

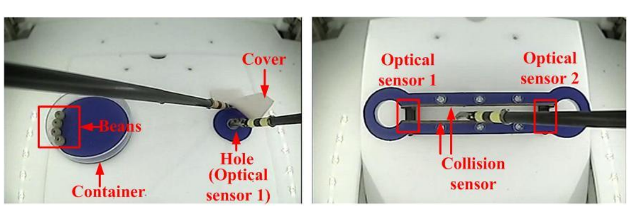
The grip and stability module use similar circuit and are both embedded an 8-bit MCU. The different part is that we only use optical sensor 1 in grip training module and use optical sensor 1, sensor 2, and collision sensor (J1 and J2) in stability training module. To detect the slot signal, the output of optical sensor 1 and optical sensor 2 are input to the 10-bit analog to digital converter (ADC) which is embedded in the MCU. If the reading of ADC is larger than a threshold voltage, it means there is an object pass through the slot of optical sensor, and then the MCU sends the corresponding message to a PC via the UART port.

C. PC Client Software and User's Interface

The laparoscopic surgery training software is developed by Visual Studio MFC, and the virtual auxiliary screens are developed by computer graphics with OpenGL libraries. The user's interface is displayed on a 22" LCD monitor (1920×1080 pixels) and shown in Fig. 4, the part (1) is the real time video in the training box that is taken by the endoscope or webcam, the part (2) and (3) are the top and left view of assist images which are using the OpenGL to present the simulating surgical training environment and the location of the instrument. The trainee could observe the depth and the location of instruments through the two virtual assist screens. The part (4) in Fig. 4(a) displays the consuming time and the number of beans is finished. The part (4) in Fig. 4(b) displays the consuming time and the number of collisions. There are also have two icons for "restart the game" and "query the record". In addition, the thread technology is used here for increasing the efficiency of program. There are four threads for real-time video recording, image recognition, OpenGL assist image drawing, and UART data transmission separately.

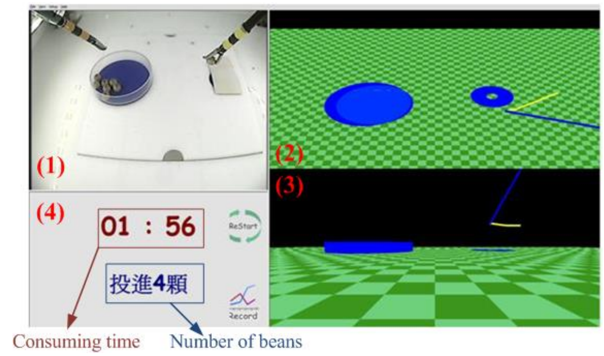
D. Image Recognition Unit

The purpose of the image recognition unit is to track the tip location of instrument in order to build a visual assist image, stability evaluation of hands' movement, and even the VR applications. The "cognitive distance" feeling provides human a rich depth of field information in the real world. However, the depth information maybe lost due to image of monocular camera. In order to solving this problem, this paper provides 3D visual auxiliary screens which is using binocular camera to reconstruct the auxiliary images. We labeled two markers on upper edge of the grasper to serve as feature points for image recognition. In order to know the location of the surgical instruments in the training box, a 3D vision range finding method has been used to calculate the instruments' tip coordinates in space.

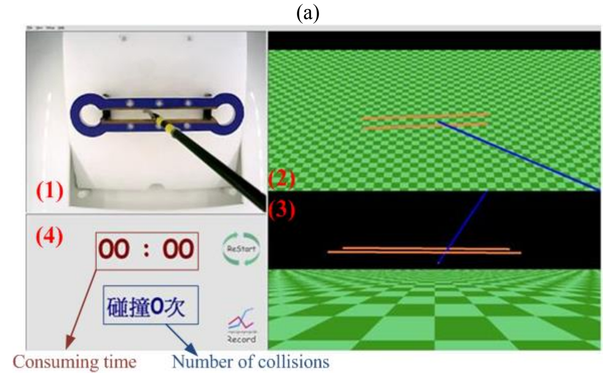


(a) (b)

Figure 3. (a) Grip training module and (b) stability training module.



(a)



(b)

Figure 4. The user interface for (a) grip training and (b) stability training.

III. EXPERIMENTS

In this study, a pilot experiment for grip training module was designed to know if this system can assess the user's capability of grip skills and the training performance after a five-day skills training program. The following description is the experiment methods.

A. Skills Assessment

In grip training module, the user needs to clip 10 beans into a hole. The system will record the starting time and ending time automatically while the first and last bean pass through the hole. The operating time will become an indicator to assess operator's grip skills and hand-eye coordinates. If operating time is shorter, then the proficiency is better. On the contrary, if the operating time is longer, said lower proficiency. In order to verify if this system can recognize user's capability of grip skills, 4 junior residents without laparoscopic surgery experiences and 6 senior surgeons are inviting to use the grip training module for three trials. At the beginning, subjects could operate the system for 1 min to familiar this system. The author also teaches them the rules and user interface for this task step-by-step.

B. Evaluation of Skills Training Performance

In order to evaluate the training performance after a five-day skills training program, 5 subjects without laparoscopic surgery experiences participate in this task. Everyone perform the grip task three trials every day for 5 days. The consuming time in each trial would be used to evaluate the training performance.

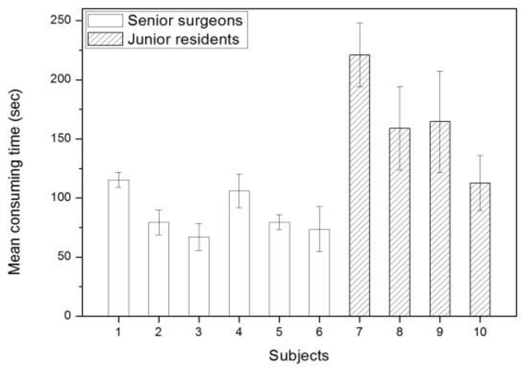


Figure 5. Assessment results of grip skills.

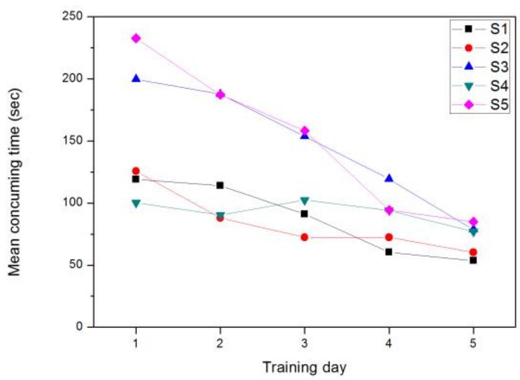


Figure 6. Training curves of five subjects in five-day grip training.

IV. Results and Discussion

The assessment results of grip skills for senior surgeons (subject 1-6) and junior residents (subject 7-10) are shown in Fig. 5. Statistical values are given as mean ± SD. The mean consuming time of senior surgeons is 86.83 ± 11.3 sec; the mean consuming time of junior residents is 164.25 ± 32.2 sec. Both mean and standard deviation of consuming time on senior surgeons is smaller than junior residents. Therefore, the results show the senior surgeons have better grip skills than junior residents. Besides, the mean consuming time of senior surgeons can also be served as a reference proficiency time (RPT) for trainees. Fig. 6 shows the training curves of 5 subjects in five-day grip training. The mean consuming time between last day and first day for subject 1 to subject 5 are improved by 54.9%, 52.0%, 60.6%, 23.3%, and 63.5% separately. The mean consuming time for the 5 subjects is 70.93 sec in day 5; the results also show the trainees can achieve a RPT after five-day training program by using this system.

Besides, this system also provides an easy-to-use user interface and the design has several features, including replaceable physical training modules, automatic quantification assessment, selectable video sources, 3D visual assist and coordinate tracking of instruments, real-time video recording, and database management.

V. Conclusion

In this study, a PC-based laparoscopic surgery skills training and assessment system was designed and developed. This system provides replaceable physical training modules, automatic and objective skills assessment, training process and results recording, as well as 3D visual auxiliary screens. The results of pilot experiment show that the system can be used to distinguish different laparoscopic-assisted grip ability level between the senior surgeons and junior residents. On the training performance, the training system can enhance user's skills in the operation of instruments was also proved. Therefore, it would be a helpful tool for basic laparoscopic skills training. In the future, more physical training modules will be designed and implemented for this system, such as suturing and cutting training modules. Besides, to combine with the 3D coordinate tracking of instruments to develop advanced skills assessment methods is also available in this system.

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