Robotic Surgical training simulation for dexterity training of hands and fingers (LESUR)

Sriranjan Rasakatla
Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan
infibit@gmail.com

Ikuo Mizuuchi
Department of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan
mizuuchi@cc.tuat.ac.jp

Bipin Indurkhya
Department of Computer science, Jagiellonian University, Cracow, Poland
bipin@agh.edu.pl

ABSTRACT

We present a software simulation system called LEap SURgical simulator (LESUR), which incorporates a human computer interface device, Leap, developed by Ultraleap Inc., to give users training in using their hands and fingers in a dexterous way, especially for surgeon trainees. There are two interaction systems in the simulator. One is for coarser dexterity training using a Kuka style robotic arm (Leapulator), and the other is a low-cost method for surgical training that can be used with a Da Vinci-like robotic surgical system. Existing surgical simulators, like the 3D systems' Touch and Phantom devices, do not give enough dexterity training for finger motion. In particular, for laparoscopic and minimally invasive surgical systems, it is necessary to acquire skills with fine finger motion and dexterity. Our simulation system aims at developing superior expertise for trainees. We use a Leap motion device to capture the finger motion and a two-mode simulator to provide different levels of dexterity training.

KEYWORDS

Surgical, simulator

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1 INTRODUCTION

All style There are many commercial robotic surgical simulators for example one such company produced system by Simulated Surgical Systems, provides a stand-alone surgical simulator called the RoSS™ platform [Robotic surgical simulator 2020]. This system teaches a novice surgeon the cognitive skills to operate a Da-Vinci surgical robot. RoSS™ uses virtual reality coupled with an electromechanical platform to aid surgeons in comprehensive surgical procedures. Simsurgery [simsurgery 2020] provides a surgical simulation platform called SEP, which is a virtual reality simulator for laparoscopy. DBox is a manual training hardware that is to be used along with SEP. Using SEP one can get training in various types of surgeries, such as cholecystectomies, ectopic pregnancy procedures, ovarian cystectomies and nephrectomies. Another company, Delletec [Delletec 2020], provides real surgical procedure simulators. This simulator mimics various organs and surgical scenarios, such as the presence of a tumor, with softness and structural fidelity using rubber elastopolymers. Several simulations of appendectomies, breast biopsies, herniorrhaphies, laparoscopies, lap sim insertions, and skin closures are provided with it. The company Surgical Science has developed Lapsim and Endosim [Surgical science lapsim and endo sim 2020.] simulators. Lapsim comes with a haptic interface in which the surgeon feels the feedback from a joystick as if holding a surgical tool while making an incision and working through it. It comes with an ever expanding library of modules that provide basic and advanced laparoscopic training. The company 3D Systems [3D Systems surgical simulators 2020], formerly known as Simbionix, has developed several simulators with haptic feedback and artificial muscles, especially the Angio Mentor simulator, Arthro for orthopedics, Pelvic Mentor for simulating the pelvic space, the Da-Vinci surgical simulation system, and LAP Mentor which comes with a haptic feedback. These modules are continuously updated according to surgical advancements in the field. None of the surgical simulators mentioned above give dexterity training for hands, especially not for fingers, which is an important aspect in doing medical surgeries. Our simulator is designed to help bridge this gap.

2 MOTIVATION AND STATE OF THE ART

Robotic technology is gaining increased acceptance in surgical procedures and is offering much more dexterity and precision than the human hand in operative procedures. This requires newer interfaces and newer types of robots that include different micro-sensors to plan minimally invasive procedures. An inexpensive surgical simulator, such as our LESUR system, would help train surgeons for advanced surgical procedures. A study reported by Howe and Matsuoka [Lapmentor surgical trainer 2020] describes minimally invasive procedures, image-based procedures, interaction modes, limitations of robotic surgery, and particularly the robotic surgical methods for orthopaedic surgery, neurosurgery and general thoracic surgery where training and simulation are important aids before doing real surgical procedures. Human surgeons are prone to tremor and fatigue, their hands might shake and tremble, whereas a robotic surgical device is stable and untiring. Our LESUR simulator

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uses a low-pass filter to overcome the hand tremors and makes the surgical simulation more stable. Many research labs and companies understand the importance of surgical training through simulation in order to hone a trainee's sensory motor skills. A complete realistic simulator of a surgical procedure is not possible with today's technology because the tissue-tissue interactions, tool tissue interactions, organ and tissue interactions, and the surgeon's hand interactions in open surgery present many complex problems of simulation. This paper [Howe and Matsuoka 1999] mentions that much work has been done on surgical simulation but little attention has been given to the kind of interfaces used. Simulation can be with or without a haptic interface. Westebring's [Westebring-van der Putten and Goossens 2008] paper mentions some important aspects like haptic interfaces, hap- tic rendering, haptic recording and haptic playback. Westebring has also worked on force reflecting hardware by calculating the interaction between the tool and the tissue. Another paper [Sagar 1994] describes an accurate model of the eye, a virtual environment to be used in surgical simulation. The simulation framework of the eye was based on a large formation finite element method to be used for a micro-surgical and teleoperated robot simulation. Virtual reality [Krummel 1998] offers advanced human computer interfaces that allow a person to travel, feel and mimic the real world. It is an indispensable tool to experience surgical conditions and so we used it in our LESUR simulator. With this surgeons can hone their skills and improve their performance during real surgeries. Preoperative planning and simulations are critical for real time success. In another example [Padov and Hager 2011] a Kinect camera is used for recognizing gestures and controlling a Da-Vinci robot to do gesture-based surgery. Some researchers have also controlled the robot Nao [Veltrop 2011] via the Kinect, which does skeletal tracking so that hand elbow motions are transferred to control the individual degrees of motion of a robotic arm.

3 DESCRIPTION

The simulator environment for these robots, LESUR and Leapulator, was built in Google Sketchup and a physics plugin named Sketchy Physics. It was used successfully to build and test a modular legged robotic system in the past [Rasakatla 2010]. Now the same simulator has been used to design the virtual surgical trainer robot (LESUR) and the virtual six degrees of freedom robotic arm, each for providing training at a different level of dexterity. Our surgical robot has been designed with long slender arms like a laparoscopic setting. There have been several surgical simulators for the Da Vinci style robot but the Da Vinci system, or the trainer, does not capture all the degrees of motion of a human hand. The LESUR and Leapulator devices are better at catching such degrees of freedom and thus become a natural interface to any system, especially surgical ones. For example, scissoring is a pinch like action which is captured by the motion between the ring finger and the thumb.The simulator has been designed to give a 3D stereoscopic view onto the artificial organ that is being worked upon during the training Each of the robotic arms has seven degrees of freedom. There are additional two interdependent degrees of freedom that are used for the scissoring action at the end effecter. Each of the robotic arms has five rotary and two linear degrees of freedom. A surgical simulation should not show erratic and abrupt moves, so the degree of motion of the arm was limited and the gains were reduced. Initially, the arm did not physically interact with the organ, but in a later version, collision detection was incorporated for the interaction between the end of the arm and the artificial organ. A human hand cannot be positioned as precisely as a robotic tool for surgery due to its natural size and its tendency for tremor and fatigue. To overcome this problem, we devised an audio cue that changes its tone for the slightest displacement. This way the surgeons will get to know precisely when they are in position and can train themselves with minimal tremors. This will prove invaluable in laparoscopic minimally invasive surgery. The position of the hand from the Leap API is transformed to the physical model of the robot, and then the motion is sent over TCP/IP to an FFT audio filter to provide a sound sample from the processing software. There the pitch of the generated sound is linked to the position of the arm, with the audio cue, tiny to moderate vibrations will change the pitch of the sound. This feedback can be used by trainees to improve their training. Leapulator is the simulator for controlling a virtual robotic arm with a leap motion controller. This mode was designed to give a coarser dexterity experience at the beginning of the training. After the trainee feels comfortable with this, finer dexterity training is given in the laparoscopic mode. The manipulator used here is the virtual model of a six degrees of freedom manipulator designed in the universal simulator and control environment. This was designed to test whether Leap motion device can be interfaced to such hardware in an easy and intuitive manner. The robotic arm has three degrees of freedom, whereas the end effecter itself can rotate with 3 degrees of freedom. The motion of the palm was linked to the simulator API via the Leap motion API. Hand motions in three fundamental directions were tied to the arm's degrees of freedom. The pose of the palm, calculated as pitch, yaw and roll, was linked with the degrees of freedom of the end effector. During the initial development, the motion of the palm in the 3D coordinate system, from its mean position as calculated by Leap API, was linked to how the robotic arm would operate its degrees of freedom. The linear translation freedom of the arm was converted into the rotary degrees of freedom of the arm and, finally, the pose of the hand was assigned to the tool-head pose. Given that servo motor control was already developed for the universal API [Rasakatla 2010], if a real robotic arm was constructed, this gestural interface could be immediately operated with the same API. This is one advantage of using our universal simulator and the API approach.

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