

Development of a Physical Interface to Interact with a Virtual Laparoscopic Environment

Daniel Posada, Christian A. Diaz, Helmuth Trefftz and Jorge Bernal

Abstract—Nowadays, training process for laparoscopic surgeons is based in interacting with experienced surgeons during procedures in a surgical room. However, the Development of specific skills involved in laparoscopic surgery, claims for new training methods and tools.

The virtual surgical simulators make possible for surgeons to train and polish their techniques. These simulators have two different components: the user interface and the virtual interface. Developing the physical user interface requires mechanics to study the movements and forces involved in the interaction between surgeon and laparoscopic instruments, and developing the virtual interface requires tool like computer graphics and physical simulation in order to simulate in a realistic way a surgical task.

The current project shows the process to integrate a mechanism that simulates degrees of freedom existent in the laparoscopic surgical procedures with the essential devices to acquire digital information from the real environment, used to rebuild the virtual environment. This information represents laparoscopic instrumental position and its state, which may be open or close. This also shows the results obtained when the test is performed to corroborate the utility of the physical and virtual interface, comparing it with a real training device and evaluating the effectiveness of both. The results obtained indicate that there is not a meaningful difference between people who uses the real training device and the virtual training device developed.

Keywords— Minimally Invasive surgical, surgical simulation, surgical training

I. INTRODUCTION

The current model of learning and training in laparoscopic surgery is based on observation and participation of new surgeons during procedures, taking active roles depending on their experience [1]. Unlike open surgery, Minimally Invasive Surgery (MIS) requires developing different skills due to the lack of haptic and visual feedback [2]. This makes necessary to

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D. Posada is with the EAFIT University, Virtual Reality Laboratory (corresponding author to provide phone: 057 2619500; e-mail: dposadas@eafit.edu.co).

C. A. Diaz, is with the EAFIT University, Virtual Reality Laboratory (corresponding author to provide phone: 057 2619500; email: cdiazleo@eafit.edu.co).

H. Trefftz is with the Eafit University, Virtual Reality Laboratory (corresponding author to provide phone: 057 2619500; e-mail: htrefitz@eafit.edu.co).

develop new specialized ways of MIS training.

The advances of new technologies in fields as modeling biomechanics of living tissues and virtual environments has created the conditions for surgical training to meet all key elements to obtain an efficient outcome [3]. The virtual laparoscopic simulators have no limitations of time, or risk unlike conventional methods of training, which could further jeopardize the health and even the lives of patients. The present project is intended to abolish limitations faced by surgeons in laparoscopic procedures, to practice their techniques in order to improve and enhance their skills.

This project aims to provide a solution to the user interface of a virtual surgical laparoscopy simulation system. Through the study of mechanical and physical principles that are involved in the procedures, the mechanism is designed and built considering the boundary conditions to replicate the movements of a surgeon, integrating the devices that help capture signals, which are relevant to generate interaction with the virtual environment.

II. RELATED WORKS

Several physical interfaces have been developed in the medical field with applications as navigation attendance in biopsy [4], a surgical simulator to hysteroscopy [5], a catheterization simulator [6], between others.

Some progress in virtual simulation surgery, are achieved by using certain devices in a physical interface, these are used to track instruments position and some provide tactile feedback to the user.

However few works in physical interfaces to training in laparoscopic surgery has been yielded [7]. The company immersion corporation was the first that develop a intuitive device which allows interact with a virtual environment to simulate a surgical procedure [8]. Today have been developed two interfaces specialized to the interaction with simulators of laparoscopies procedures, which gives haptic feedback and tracking the position of the instruments.

Other device developed to applications of laparoscopic surgery is The HIT Force Feedback Device. This haptic device with five degrees of freedom has been designed by

Hauptabteilung Ingenieurtechnik. This has 3 degrees of freedom in its haptic feedback and has been composed to the surgical simulation system KISMET [9].

This project has the intention of describe the development of a physical interface for its composed with a virtual environment of surgical simulation. The same way, trough experimental tests it wishes corroborate in front of conventional physical device its effectiveness in the training of a surgical task as the transport of objects to an objective common using the surgical instruments.

III. DESCRIPTION OF THE SYSTEM

Next will be describe each one of the phase done to design and build the physical interface and the virtual environment.

A. Movements Analysis

The analysis of mechanics in the virtual surgical simulators represents an important field of study in the process of design and construction of the physical interface.

The laparoscopic procedures, implement five degrees of freedom in the instruments. The five degrees of freedom, or DOF for its acronym in English, are described in detail below:

Pitch: This degree of freedom allows tilting the instrument on a horizontal plane. Its measurement is done in degrees, looking at the instrument from top (Fig. 1), the movement that originates is a turning inward of the shaft, either clockwise or anti clockwise.

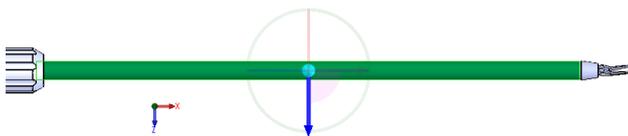


Fig. 1 Inclination (Pitch)

Yaw: This degree of freedom allows rotating the instrument on a vertical plane. Its measurement is done in degrees. Fig. 2 shows the side view of an instrument, turning on this occasion is done around the green axis.

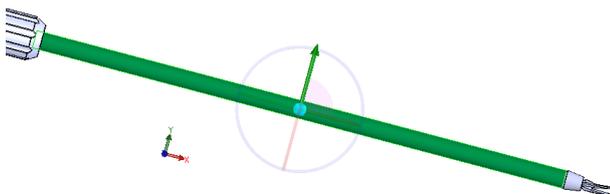


Fig. 2 Rotation against a vertical Plane (Yaw)

Insertion: This degree of freedom allows the instrument to

move lengthwise into the belly of the patient. Its measurement is made in millimeters. Fig. 3 shows the longitudinal displacement; this is parallel to the axis of the instrument.

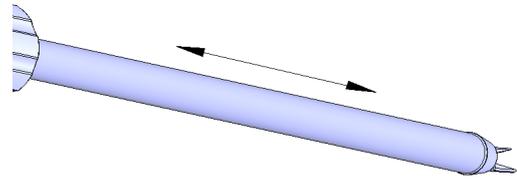


Fig. 3 Shaft displacement of the instrument (Insertion).

Rotation: This degree of freedom allows the instrument to rotate on its own axis in order to give a specific position at the instrument. Fig. 4 shows a side view of the instrument.

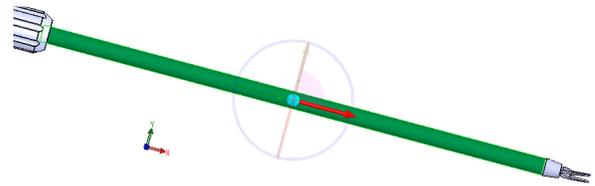


Fig. 4 Rotation on the shaft of the instrument (Rotation)

Handle: This degree of freedom allows the tip of the instrument, to open or to close. Fig. 5 shows the movement generated.

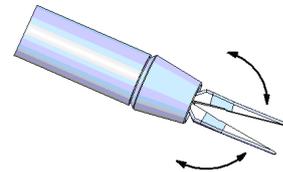


Fig. 5 Open or close the instrument (Rotation)

B. Design and Development

When designing a mechanism to satisfy laparoscopic surgery movements, it is important to consider the classification of kinematic pairs; this can be done by three different criteria [10]:

- The number of degrees of freedom in the bar connected by the pair.
- The type of contact between cells.
- The manner in which the elements remain in contact.

The classification of kinematics peers in terms of DOF number and relative motion between the elements of peer kinematics according to the degrees of freedom in this classification, there are two conditions that impose an upper and lower limit to the DOF number, these conditions are:

- The kinematic pair must allow relative movement

between the elements. Therefore, there must be at least one degree of freedom in the relative motion.

- The elements linked together by the pair, must remain in contact. Hence, there should be more than five degrees of freedom in the relative motion between the links.

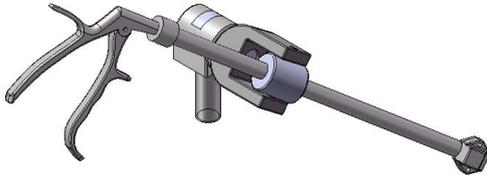


Fig. 6 Preview design of the user interface

Once you have determined the upper and lower limits on the number of degrees of freedom of movement to allow kinematics in a pair, it is possible to classify them in a comprehensive manner.

The pursuit of the pair to comply with the DOF design requirements for the physical user interface concludes finding a pair of class IV type cylinder field Ec.

C. Acquisition System

The operation of the virtual interface requires information such as the instrument's spatial location manipulated by the user and its state, which can be opened or closed, as mentioned in the previous section. The instrument state is reproduced in virtual surgical environment, in order to provide more realistic laparoscopic procedures simulations.

Below are the devices that need to be integrated into the user interface physics, in order to obtain the relevant information in the reconstruction of the virtual interface.

Magnetic Position Trackers

The Trackers are also known as 6 degrees of freedom devices. They identify the position as coordinates (x, y, z), and the amount of rotation in each axis, the latter are known as yaw, pitch and roll in English, respectively. In hardware terms, a source is needed to generate signal, a sensor that receives signals and a control component that processes the signals and can communicate with the computer. Depending on technology to be applied, one of two, sensor or source can be anchored to a body, serving as a reference.

Within position trackers there are those whose operating principle is magnetic, they use a radiation source and a magnetic sensor that calculates the position and orientation with respect to the source of radiation. There are devices that

provide systems with multiple sources and their associated sensors that track the position up to a frequency of 100 Hz at ranges from one to six meters, providing a fairly high accuracy. A drawback of these devices is metal objects may distort the magnetic field, providing erroneous readings. [11]

The virtual laparoscopic simulators, implement five DOF in its physical interface, an example of this is the simulator is the one produced by Immersion Corporation. The magnetic tracking devices allow position digitalization in real time up to four of the five degrees of freedom that implements a conventional laparoscopic simulator; this represents an 80% of movement in the user interface.

This project uses a magnetic position tracker supplied by Polhemus patriot, this has been integrated to the user interface anchoring the tracker source to the chassis and using two sensors on the mechanisms that simulate laparoscopy forceps. This makes possible to measure motions of the instruments to a reference point.

Analog to Digital Converters

The angular separation between a handles pair, can be read as a signal with a maximum amplitude when the handles separation is maximum, and minimum amplitude, when separation between the handles is too small or zero. For acquisition and digitalization of this information in the user interface, a microcontroller is used, this includes analog to digital converter (ADC).

The most common A/D converters can work with an 8 or 10 bits resolution, using as a higher value the decimal number corresponding to $11111111 = 1024$. For instance, if using an 8 bits A/D converter, where $V = +5\text{ V}$ and $V_{ref} = 0\text{ V}$, resolution is $5\text{ V} / 255$, when the analog signal is 0V has a digital number equal to 00000000 and when the signal is 5 V has a digital number equal to 11111111.

The selected microcontroller that meets requirements of transferred amount of data and how to transfer it. The main conditions for microcontroller are:

- Minimum two-channel ADC
- Possibility of USB communication
- High speed communication, between 20 and 48 MHz

The selected microcontroller for the project, which complies with the features mentioned above, is a microchip 18F4455. This includes up to seven A/D ports and USB communication.

D. Integrating the Interface to Virtual Environment

In daily life there are many examples of interface; one of

them is the interface car-driver, in which the user interacts with a vehicle through controls. In laparoscopic surgery, the surgical instruments are the interface between surgeon and patient. It is very important to realize that a first-level interface reflects the physical qualities of the two interaction sides. The instrument is made of a solid material and has some restrictions on its movement; on the other hand, to interact with the surgeon it is located at an appropriate altitude. This is a very important idea in the design that can be described in two concepts [12]:

- Visibility: to be able to perform an action on an object must be visible.
- Intuitive: understanding or being clear on the part of the object that is going to take an action and how to do it.

Once you meet these concepts in the user interface, there is a successful interaction with the virtual interface, which is built using the information captured from real environment, using devices like the position trackers and the analog to digital converter mentioned before; using mathematical models to recreate the mechanical human organs behaviour, reproduce their deformities upon the effect of efforts. This virtual configuration used for the experimental test consisted of three cubes on a surface, which ought to be grasped with the surgical devices by the user and then transported into a clear area. In order for the virtual environment to achieve a larger realism, simulated physical characteristic of the cube movement, such as free fall between others. The Fig. 7 shows the virtual environment of the system.

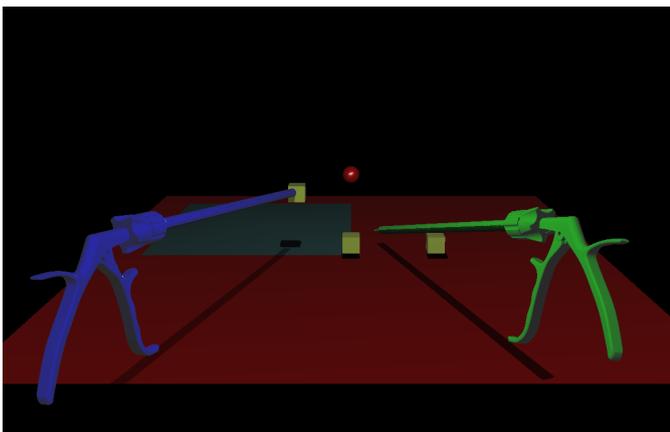


Fig. 7 Virtual Environment developed to experimental task.

IV. EXPERIMENTAL SETUP

The proposed hypothesis that wants to be proven through the virtual environment and physical interface developed is to determine if by a user that train with a virtual environment obtains the same skill level that a user that train with a real

TABLE I
RESULTS OF THE EXPERIMENTAL GROUP
Virtual Environment

Subject	Initial Time (s)	Final Time (s)	Time Delta	Improvement Porcentaje (%)
Subject 1	25,6	16,2	9,4	36,71
Subject 2	23,1	15,3	7,8	33,76
Subject 3	59,1	28,3	30,8	52,11
Subject 4	51,7	34,7	17	32,88
Subject 5	77,9	43,9	34	43,64
Subject 6	95	37,9	57,1	60,10
Subject 7	55,8	21,9	33,9	60,75

environment, that is, conventional tool using in a normal curriculum. With the aim to prove our hypothesis, an experimental test was developed. Two groups of subjects who did not have previous knowledge or experience about related concepts to minimally surgical procedures and open surgical procedures were used during the trial. The first group, called control group, had 7 subjects and the training session was done by a conventional tool. The second group also had 7 subjects and the training session was done using a virtual environment. Both groups had to take a pre-test to determine their skill level before the training session, and after the session they had to

TABLE II
RESULTS OF THE CONTROL GROUP
Real Environment

Subject	Initial Time (s)	Final Time (s)	Time Delta	Improvement Porcentaje (%)
Subject 1	28,1	16,9	11,2	39,85
Subject 2	27,9	17,8	10,1	36,20
Subject 3	33,8	14,1	19,7	58,28
Subject 4	65,3	30,9	34,4	52,67
Subject 5	22,7	12,3	10,4	45,81
Subject 6	19,7	9,7	10	50,76
Subject 7	40,2	10,4	29,8	74,12

take a post-test to determine the skill level reached after the training session. The defined task to execute during the training session to both groups is grasp and transport some objects to a specific site. Each person of the group that used a virtual device and of the group that used the conventional device, in the training session did ten repetitions of the task to acquire the necessary skills to do that task.

The conventional device used by the control group is a set of mirrors, which are useful to change the pint of view of the zone where do the task, this to simulate the effect generated by the point of view of the camera in a laparoscopic procedure. Also, has two support above which are the surgical devices and allows the degrees of freedom of the movement in agreement to the scarcely invasive procedures.

V. DISCUSSION AND RESULTS

As is mentioned before, the control group and the experimental group, do a pretest and posttest, in which did the

task will be train, and its performance was assess measuring the time to do this task. The pretest and the posttest of both groups were made in the conventional tool, in a real environment. The results obtained in the pretest and the posttests to both groups are in the Table I and Table II. The same way, the Table I and Table II shows the difference of the time between the pretest and the posttest to each person, and the percentage of performance.

From these two variables to make the test t- student to reject a null hypothesis the both groups had an improvement of time and a percentage of performance similar, through of a comparison of theirs averages. The meaningful statistical was $P < 0.05$ and it used the StatGraphics Software to do the data analysis.

The t-Student test shows that is not possible to reject the null hypothesis and both groups to improvement time case and the performance percentage case are similar, when are compared with theirs averages.

Moreover, during the repetitions of the task in the training sessions to both groups, measuring the time of the finish the task, to observe the advance of the learning curve of each person. In the Fig. 8 y Fig. 9 is possible to observe the learning curve of each person, of the experimental groups and of the control group respectively. Is visible how converges the task to the minimum time required by the task for its execution.

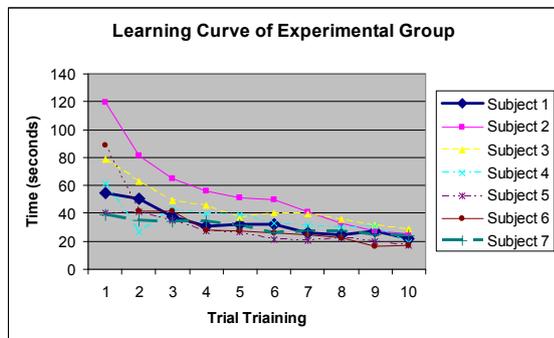


Fig. 8 Learning curve of the experimental group.

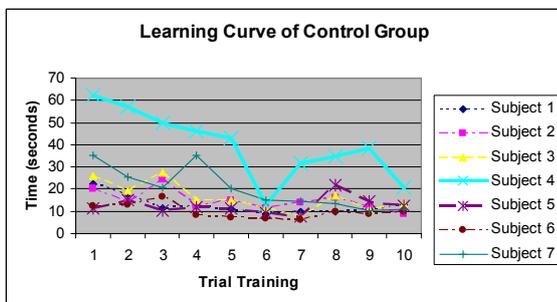


Fig. 9 Learning curve of the control group.

Similarly, during the repetitions of the task in the training sessions of the experimental group we measure the magnitude of the trajectory of the instruments. In the Fig. 10 we show how the magnitude of trajectory decrease whiles the training advance.

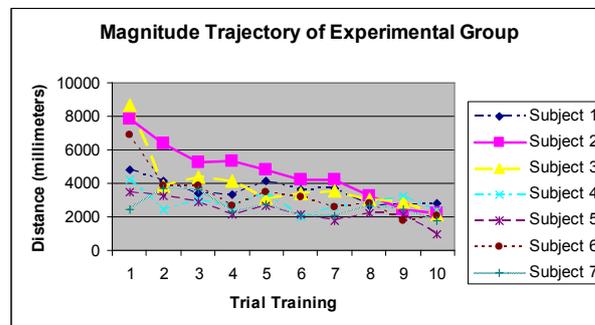


Fig. 10 Magnitude trajectory of the experimental group.

After the session, the subjects of the experimental group answered a questionnaire about the virtual environment, physical interface and about their impact in the skill training of the task performed. Several subjects agreed that the use of virtual environment and physical interface is intuitive and the movements of the instruments in the virtual environment and real environment are similar.

VI. CONCLUSION

Based on these results we can concluded that the performance of the experimental and control group are similar, demonstrating the potentiality of the virtual environment and physical interface to transmit the skills to the real environment.

Following the physical interface and virtual environment developed we propose to add a force feedback to the physical interface in order to allow that the surgeon practice this clue. On the other side, we will also add more complex task to the virtual environment, like cut, suturing and manipulation of deformable objects.

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