# Virtual reality simulator for laparoscopic procedures performed with a robotic endoscope holder

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**Abstract.** The use of virtual reality (VR) simulators for training novice laparoscopic surgeons has the potential of improving psychomotor skills and reducing the learning curve on real laparoscopies. This paper refers to a VR simulator to be used with CLARA system, which is a robotic endoscope holder developed at University of Brasilia for abdominal laparoscopic procedures. It aims to train CLARA's future users at handling the robotic device, besides presenting the product in an innovative approach. The simulator was evaluated by ten students from UnB Health College which were asked to perform a simple task on the CLARA simulator twice. The total time needed for each user to complete the task for the second time was measured and compared to their first trial. The verified improvement is on average 70% in the mean response time and 37% in the mean time to complete the task for all the subjects.

**Keywords:** Surgery simulator, Virtual Reality, Laparoscopy.

## 1 Introduction

Most traditional surgeries performed currently on SUS (Brazilian Health System) require a long incision, which implies an increased risk of infection and a long recovery time on public hospital beds. The incoming of minimally invasive surgery (MIS) introduced many benefits over traditional surgeries including reduced blood loss (about 47% of traditional method mean rate) and smaller recovery time (about 67% of traditional method length of hospital stay) [1], besides less postoperative pain [2] and smaller scars, since the whole procedure is made through small incisions with the aid of a camera.

Laparoscopy is a type of MIS commonly used to execute procedures performed in the abdomen and pelvis region such as Cholecystectomy, Colectomy and Nephrectomy. Usually, it requires at least two doctors to be accomplished: one to perform the surgery itself and another one to guide the endoscope, which is a major disadvantage of laparoscopy, specially in SUS that has a shortage of health professionals, making the use of two doctors in the accomplishment of a simple procedure highly costly and inefficient.

Some alternatives have been developed worldwide to overcome this laparoscopy drawback. The Da Vinci Surgical System, for instance, contains three robotic arms holding medical tools and another one to control an endoscope, and can be commanded by a single surgeon from a console. However, the system costs on average US$ 2 million, which is too expensive for the brazilian government to fund for public surgical rooms.

Therefore, a robotic endoscope holder is being developed by University of Brasília so that a single doctor can control the camera through a joystick attached to the surgical tool while performing a laparoscopic procedure. The award-winning CLARA Project (honorable mention in Prêmio de Incentivo em Ciência, Tecnologia e Inovação para o SUS 2017, na categoria Produtos e Inovação em Saúde) has had encouraging results so far, but the conclusion of its first functional prototype is expected only for 2018. Since the device is still in testing stage, it was also necessary to have a software for testing, training and presenting the product, promoting an easier and faster integration of CLARA System to the national health system.

This paper presents a virtual reality simulation software in which a virtual prototype of the endoscope holder CLARA can be controlled through the real joystick of the system. It also contains an immersive 3D model of the surgical room and proposes a simple task to measure the user's handling of the virtual endoscope, so the surgeons are able to adapt to CLARA's displacement steps and endoscope motion velocities before actually performing surgeries.

## 2 Methods

Training of laparoscopic surgery in a simulated environment has been proved as an effective step before clinical practice [3, 4]. The main approaches for simulations include the use of phantoms and surgical models [5], Augmented Reality (AR) simulators [6], and Virtual Reality (VR) simulators [7].

While good phantoms and surgical models can provide the most realistic simulations, they are very costly, and highly dedicated to an specific clinical situation. The use of computational tools instead of physical trainers allow surgical simulators to emulate many aspects of a real surgery, while providing the user with valuable training opportunities by having lifelike graphics, various scenarios, and repeatable training modules.

AR simulators superimpose three-dimensional images over images provided by cameras, which are obtained from a real world environment that must be properly prepared for the simulation to take place. On the other hand, VR simulators create an artificial environment which can be fully controlled by the programmer. For the CLARA surgical simulator, the VR option was chosen since it provides most flexibility and less dependence on infrastructure conditions, which can be a challenge in brazilian SUS reality.

To improve the engagement and sensorial responses of the users, we have proposed an immersive 3D virtual reality which is obtained by the use of stereo vision with the aid of a smartphone combined to a VR Headset as a low-cost alternative to an Oculus RIFT, with proved efficiency without any obvious loss of performance [8].

Hence, the CLARA simulator is composed of a VR Headset to be attached to the user's smartphone, the original joystick used to control the CLARA robot, and a smartphone application that provides the immersive 3D reality and controls the virtual CLARA robot from joystick commands. As requirements, the smartphone must be equipped with bluetooth communication and a built-in IMU, besides using Operational Systems Android 4.4 or IOS 8.0 (or higher).

### 2.1 Development of a 3D model

Immersion into virtual reality is a perception of being physically present in a non-physical world; it can be reached by surrounding the user with sensorial stimuli. This sensation can enhance education by increasing the interest and absorption of the content, reducing the learning curve [9 , 10]. Therefore, the first step in the development of CLARA simulator was the creation of the environment 3D model. The software *Autodesk Maya* was used to create an immersive surgical room and a virtual patient.

The organs from the abdominal region were modeled based on the illustrations from Netter's Atlas of Human Anatomy [11] and the endoscope holder was imported from Solidworks® model used for the real CLARA robotic arm manufacturing.

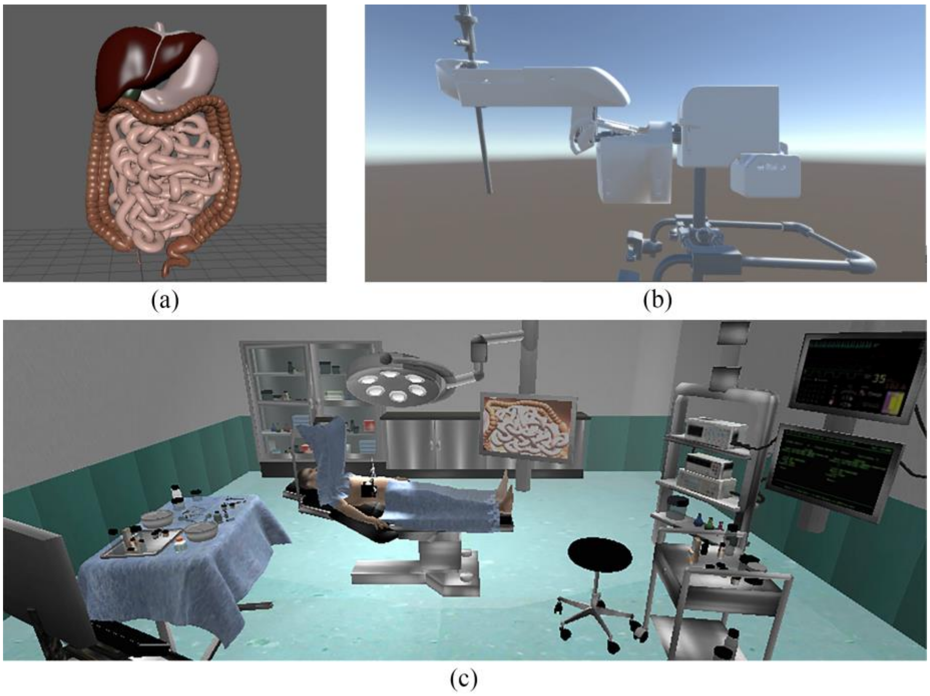



**Fig. 1.** 3D Models developed: (a) Abdomen anatomy organs; (b) CLARA robotic arm; (c) Immersive surgical room.

### 2.2 **Virtual Simulation**

Simulation is the reproduction of a real-world process or system and it can be reached by using the developed 3D model to interact with the user. Thus the model, still completely static, was exported to another software called *Unity3D* which is a cross-platform game engine that supports C# scripting for implementing the desired behaviour on each virtual object of the model. Besides that, *Unity* supports building to many different platforms including IOS and Android, chosen platforms for CLARA aiming to use a smartphone attached to a low-cost VR Headset.

**Virtual Reality on smartphone.** The first step on the simulation development was attaching a virtual reality script to the simulated camera view, thus the screen splits in two parts, for left and right eyes, which makes 3D vision sensation possible. Since the smartphone contains a 6 axis Inertial Measurement Unit (IMU) which can sense accelerations in all 3 translational axes and all 3 rotational axes, the script also integrates these accelerations to find position and velocity variation of the device, using this information to rotate the camera view to properly follow the user's head movement.

The VR script is a native package from *Unity3D* to be used with *Google Cardboard headset,* which is a low-cost head mount for smartphones developed by Google. The two splitted views are displaced precisely so that the distance between two 45mm focal lenses and the smartphone screen creates the 3D perspective in a pleasant way for the human eyes. The chosen VR Headset for CLARA simulator was not *Google Cardboard* due to its low material resistance, but a similar plastic model that presents the same dimensions so that the Unity VR package can be used without adaptations.

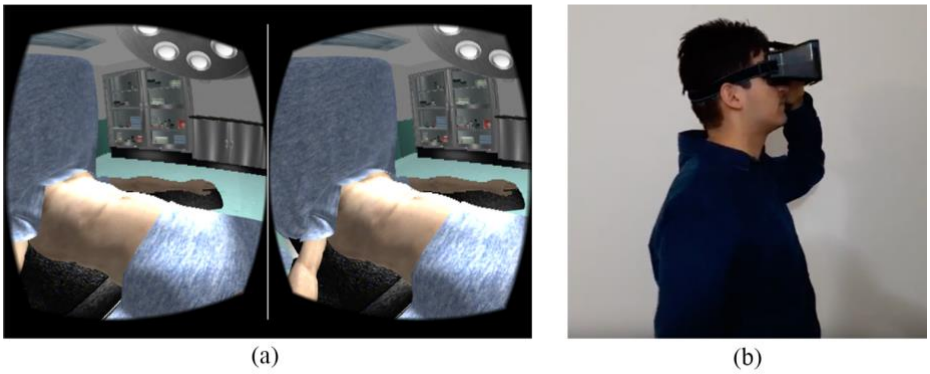


**Fig. 2.** (a) Simulation screen divided into right and left eye; (b) Virtual reality headset used for CLARA simulator.

**CLARA endoscope holder simulator.** The mathematical model that describes the robotic arm motion must regard two important features of the real CLARA robot: the parallelogram rule and the mechanical link of the pieces.

*Parallelogram Rule:* During the laparoscopy, the endoscope is inserted through orifice on a small incision on the patient's abdominal wall and only moves around this pivoting point until the end of the procedure. Thus, it is indispensable that the endoscope holder can keep this entry point constant to prevent the endoscope shaft to injure patient's tissue. Aiming for it, the CLARA mechanism was projected to keep the position of the endoscope zone aligned to the lower rod of the robotic arm, as illustrated in points *A* and *B* from Figure 3 (b). This is achieved through a parallelogram mechanism, in which all the opposite rods must be parallel, as illustrated in Figure 3 (a), so that backward and forward movements will change the angle of the vertical rod and the position of the upper horizontal rod, but never change the distance between points *A* and *B*.

*Mechanical link:* The mechanical behaviour simulation of each piece of the robotic arm was set individually so that the entire virtual system can operate identically to the real endoscope holder, since its position and rotation in all axis are calculated and external forces are considered, such as gravity and friction. In practice, there is a cursor being controlled by the joystick commands and all other pieces are adjusted at each frame to geometrically fit the cursor new position and the parallelogram rule.

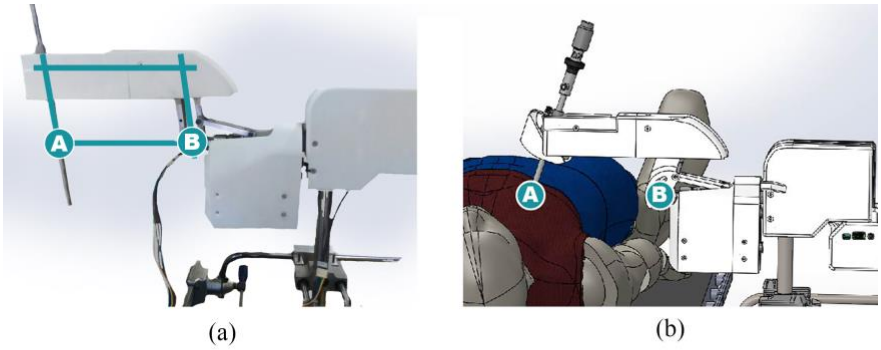



**Fig. 3.** (a) Real robotic arm illustrating the parallelogram rule; (b) 3D model of the robotic arm illustrating incision spot 'A' and the fixed reference of the mechanism 'B'.

**Receiving Joystick Commands.** The device attached to the medical tool contains a Bluetooth 4.0 chip associated to a microcontroller which sends a data bundle containing the data read from joystick at each time instant. Figure 4 illustrates the implemented script for receiving this data through the smartphone bluetooth and using it to move the virtual cursor.

The command script consists in finding the name and subscribe ID of CLARA joystick and wait for it to send data. When data arrives, if it is a recognized command (Right, Left, Up or Down) the cursor position is updated based on the pointed direction. If elapsed time without incoming data exceeds 10 seconds, it is supposed that joystick has disconnected and the whole process is restarted.

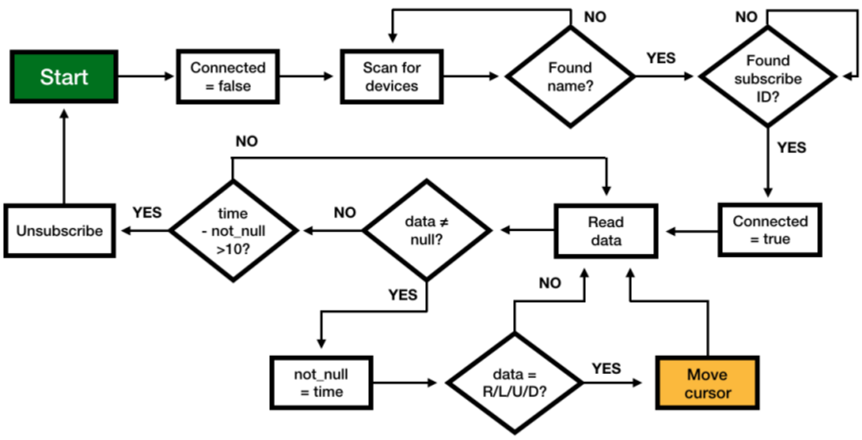



**Fig. 4.** Fluxogram of the bluetooth script used to receive joystick data and move the cursor

### 2.3 Task for Training Evaluation and Simulator Validation

In order to evaluate the real improvement of the psychomotor skills of the users, a quantitative study was made with ten students from UnB Health College in which a simple task should be completed using the CLARA simulator.

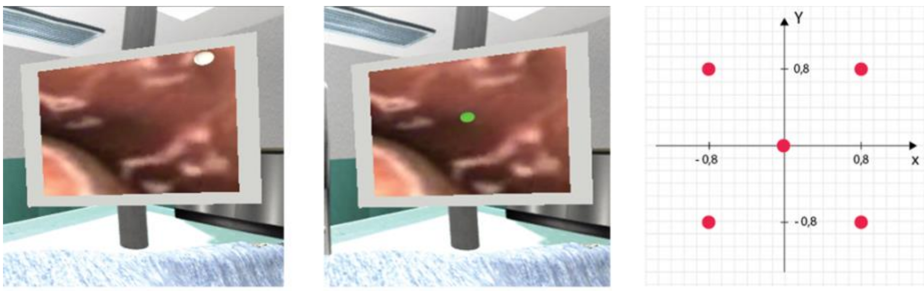
The task consists in moving the virtual endoscope while attempting to reach a goal, which is positioning the small sphere shown in Figure 5(a), at the center of the virtual monitor, such as illustrated in Figure 5(b).

During a setup phase, the sphere is positioned close to the center, and the user has the opportunity to test the joystick operation before the task time is accounted for user performance. Once the center is reached, the task begins and a starting position for the sphere is initialized.

The sphere admits 4 different initial positions, as shown in Figure 5(c), that alternate between each other and must be moved around by the user to reach the central point. After a success, another initial position is randomly selected and the user is asked to reposition the sphere, repeating the task for 4 times in total per trial.

To determine whether the target is reached or not, the central position of the virtual screen and the center of the sphere are compared. If its difference is smaller than a threshold Δ=0.05 (on local units reference) the hit is accounted. Also, the sphere must be held at this position for 500ms before the achievement is validated.

At each simulation frame, the position and time are saved to be compared to previous trials in order to generate quantitative data to be analyzed. Besides that, all the subjects who took part on the test filled a form evaluating the simulator and the task, generating also qualitative data from possible future users of CLARA. Such feedback aims for forthcoming improvements of the system.




(a) (b) (c)

**Fig. 5.** (a) Sphere of the task; (b) Target reached on the middle of virtual screen; (c) Central point, four possible positions and its distances from each other on local units reference.

## 3 Results

The mean time to reach the target was computed for the ten testing subjects and then compared to the previous trial, presenting an increase of up to 60% (for the first subject) and a mean of 37% of improvement to all subjects, except for the fifth subject whose data of the second trial was corrupted and could not be compared. The

individual mean time of each subject is shown in the bar graph of Figure 6.
All data recorded during setup phase was discarded so that the period for VR Headset adjusting, securing the joystick and finding the virtual screen the on 3D environment does not affect the results.

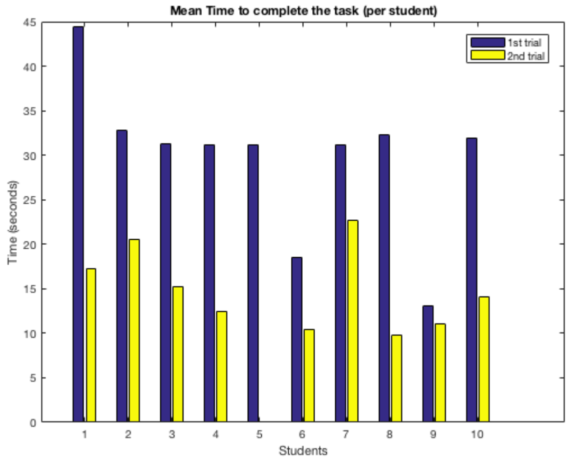



**Fig. 6.** Bar graph illustrating the mean time of each subject to complete the task on the first and second trials. The second trial data of the fifth subject was corrupted, thus it is not represented.

Figure 7 illustrates the mean distance to target of subjects 1 to 4. The grey line delimits the desired position of the target in the horizontal image axis. It can be seen that the response time increases substantially on the second trial, on up to 90% for the first subject and 72% on average for all testing subjects.

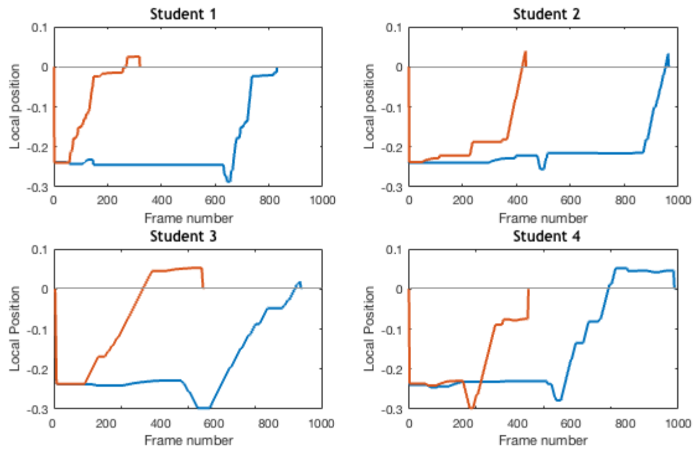



**Fig. 7.** Mean distance to target (on the horizontal image axis) for first (blue) and second (red) trials of subjects 1 to 4. The grey line delimits the desired position of the target.

Figure 8 shows the results of the form filled by all the subjects who took part on this research. It illustrates the qualitative perception of them about the simulator and the learning process associated to it. The majority of our test subjects considered the

CLARA simulator was helpful in their familiarization with the endoscope holder and the surgical procedure.

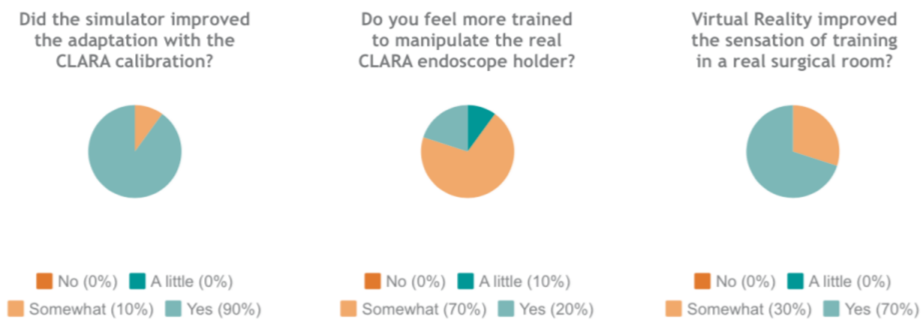



**Fig. 8.** Qualitative results of the form.

## 4 Conclusion

The obtained quantitative results suggest that virtual reality training is a good method for improving the learning curvature and response time of the CLARA joystick users, besides increasing the mean time to complete a simple task, which implies an advance on their psychomotor skills. Qualitative data indicates that the subjects felt acquainted with the device calibration after the first trial and became more confident about manipulating the real endoscope holder.

Since the real CLARA System is still in testing phase of its first functional prototype, there is no research comparing the performance of the users on the real device after the simulator training. Hence, it is still not possible to conclude that the simulator indeed improves the handling of the system on real surgeries. However, the presented results indicate that the proposed simulator has great potential as a training tool for the users of the real CLARA robot.

This leads to possible future work, which include not only comparison of user performance on the real CLARA robot before and after simulation training, but also the validation of the virtual reality training with residents and surgeons with different experience levels in laparoscopies. Future work also encloses the development a desktop version of the simulator so that the people who do not get used to the virtual reality sensation (e.g. sight problems) will still be able to use the CLARA simulator.

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