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Virtual Simulation for Scoliosis Surgery

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ABSTRACT

Virtual Reality is currently one of the most emerging innovative technologies, and over the last year we have seen how different sectors have successfully applied it ranging from the most industrial sectors to the education or medical sectors. The system presented in this article consists on a virtual simulation of a lumbar transpedicular fixation surgical operation, in order to achieve a fixation of three vertebral functional units. The user will be inside an operating room, in front of the patient, which in this case is a complete 3D model that includes musculature, complete skeleton, ligaments, veins, arteries ... The actions to be performed include selecting the right tool and subsequently its use, so that the user interacts with the system by moving his hands. The objective of this study is for the user to know the tools that should be used in this procedure and the steps that must be followed. In addition, virtual simulation merges with videos of real surgery, making this system a great tool for training in this type of surgery, demonstrating the potential of Virtual Reality as a useful technology for training. This system includes a theoretical part that shows all the steps and all the information to the user, and a practical part, in which you must interact with the system to perform each step of the procedure itself. This interactive virtual simulation has been developed by the company specialized in advanced systems of Augmented Reality and Virtual Reality ARSOFT, in collaboration with members of the Research Groups of the University of Salamanca VisualMed Systems.

CCS CONCEPTS

• Computing Methodologies - Symbolic and algebraic manipulation - Artificial Intelligence - 3D Imaging

Social and professional topics - Professional topics - Computing education programs

Software and its engineering - Software organization and properties - Contextual software domains - Virtual worlds software

KEYWORDS

Virtual Reality; Virtual 3D World Immersion; Stereoscopic Vision; Immersive System; Medical Training; Surgery; Training Virtual Tool.

1 INTRODUCTION

Although it is true that the technology of Virtual Reality has begun to popularize in the last decades, the truth is that it is not a new concept [1-4]. In 1957, pioneer Morton Heiling created his now well-known Sensorama machine. This machine (Fig. 1) was able to show stereoscopic images in three dimensions with a high quality stereo sound, even reproducing the wind sensation and certain aromas, with the aim of creating a dive as realistic as possible in the virtual world that showed. This revolutionary machine was used to reproduce films in three dimensions. Today we have taken the concept of Virtual Reality much further, including real applications, that a few years ago would have been considered futuristic and distant.

Figure 1: Advertisement for Heilig's Sensorama, courtesy of Scott Fisher's Telepresence

The truth is that since 1957 technology has advanced by giant steps, and what a couple of decades ago occupied an entire room and was prohibitively expensive. Nowadays, we carry it all in our pockets. We talk about computers, which is what we really have in today's smartphones [5-9].

This miniaturization and improvement of the processing capacity of computers is precisely what has caused Virtual Reality to become a feasible technology in our society [10-13]. And it is that the Virtual Reality needs a great capacity of calculation by the devices, in addition to high quality screens that allow us to visualize the images correctly even though the devices are only a few centimeters from our eyes.

Currently, we understand by Virtual Reality system that, in an immersive way, introduces us into a completely virtual world, where users have the sensation of being inside, since when looking at one side or another we will see what we have around us. This is achieved thanks to sensors such as the accelerometer and the gyroscope, included in most current smartphones. In the most basic systems, these smartphones are the ones that execute the software of Virtual Reality, and are introduced inside glasses that include stereoscopic lenses that contribute the three-dimensional effect. [14-18] The smartphone screen displays two pictures, one on each side of the screen. Although at first glance these images can be identical, the truth is that they have a slightly different perspective, and thanks to the glasses we will see an image with one eye and another with the other eye. It is therefore the same principle as that which applies the human vision to see in three dimensions, since each eye perceives the environment from a slightly different perspective [18].

Possibilities offered by this new technology are practically unlimited, and address a large number of areas. In this article, we will focus on its application in the educational field, and more specifically in the medical training. To this end, we have developed a system capable of showing the user a three-dimensional environment corresponding to an operating room, and explain the different steps that must be performed in a lumbar or scoliosis. This surgery involves the fixation of different vertebrae in order to correct a deviation of the spine. In this specific case, we will fix six screws in total, three on each side, in order to carry out the fixation of three vertebrae.

To date, technological limitations still do not allow the development of simulations that make the virtual environment of the real environment indistinguishable [2]. However, this system shows the potential of this technology in the medical field. An example is the ability to see through the skin, organs and muscles, making the same semitransparent to be able to visualize the complexity of the area to be operated. [3] Another example is the ability to repeat the process as many times as desired. These characteristics

would be impossible to obtain in a real environment, so we see that virtual simulations also have their advantages over training and training with real patients.
According to some studies involving 16 surgical residents, those who have been trained using Virtual Reality techniques perform operations 29% faster than those who used traditional techniques, which shows us another example of the potential of Virtual Reality in this field [4].

The simulation does not capture the different complications that may arise during surgery and the solutions for each of them, however this may be one of the future lines of work for the system. This is not, however, the goal of this tool, since it focuses on showing the basic steps of surgery and allow the user to reproduce these steps interacting with the virtual world around him, so that he himself select and manipulate the Tools with the movement of their own hands, becoming familiar with each one of them.

2 MATERIALS AND METHOD

2.1 Hardware and tools

We used a regular computer, with a great computing power, and different models of smartphones and glasses of Virtual Reality (Fig. 2).

However, more important than the hardware used are the tools that allowed us to design and implement this system. In this regard, it is worth noting the use of the Unity3D video game engine. Although this software was initially designed for video game design, the truth is that its great versatility has been used for many other purposes, one of them is the development of Virtual Reality systems.

Figure 2: Virtual reality glasses used in the study

If we pay attention to a Virtual Reality system and a video game, we will see that there really are not so many differences between the two. The truth is that when designing one or the other tasks to carry out are practically the same: design and programming of the virtual environment and its behavior and programming of interaction with the user. It is true that the Virtual Reality has certain peculiarities that must be taken into account, since the user interacts in a completely different way with the environment, since it is completely immersed in it.

Unity also offers integration with tools for developers of Virtual Reality that facilitate the implementation of the system. The Software Development Kits (SDKs) we have used for Virtual Reality development are provided by Google and Oculus: Cardboard SDK and Oculus Mobile SDK respectively. Notice that a SDK consist on a set of scripts and other resources (principally source code) that facilitate the task of programming certain behaviors, in this case those related with Virtual Reality development.

So, we have actually developed two different systems, one for Cardboard platforms, and another for Oculus or Samsung Gear VR devices.

Cardboard is a Google standard that allows you to use virtually any smartphone, be it Android or iOS, with a large number of glasses from different manufacturers that can be purchased from just 3 euros.

Oculus for its part has a model of glasses, Oculus Rift, which include screen and that must be connected to a computer with high graphics capacity, and costs around 700 € at the date of writing this article, in addition to the investments necessary to perform in a compatible computer. They are therefore less affordable glasses for society in general, although it is true that they obtain a high-quality user experience.

Halfway between the Oculus Rift and the Cardboard goggles, we find Samsung Gear VR glasses, compatible with certain mobile models of this brand.

Our system, as we mentioned before, works across platforms. However, we must take into account the interaction of the user with the virtual environment. In the case of Cardboard, we have designed an application that turns any Android smartphone with gyroscope, accelerometer and bluetooth into a remote controller. Thanks to this application we are able to recognize the movements of the user's hands, so that he will see a virtual hand that he can control with the movement of his own hands.

The Samsung Gear VR glasses, like Oculus Rift, include its own controller, so in this case the user will move this controller instead of the smartphone become command. It should be noted that Google is already marketing a new standard of Virtual Reality, which includes its own model of stereoscopic glasses: Google Daydream. In this case, this technology does include its own driver, although today it is only compatible with certain models of smartphones, so it has chosen to use the SDK Cardboard, with the goal of reaching a wider audience (Fig. 3).

In relation to the resources used, we have used 3D models of the tools provided by their manufacturers, modifying the organization of the meshes of each model to be able to manipulate them correctly according to our interests. For example, the screw fastener includes a special internal structure to be able to correctly insert the screw and to grind it once it has been fixed to the vertebra.

Figure 3: Daydream and Gear VR controllers

We have used the 3D model of a complete human body (Fig. 4), including musculature, skeleton, ligaments, arteries, veins, etc. This supposes a more complete view of the patient and its interior, although also requires a greater amount of memory in the Device on which the software is to be run.

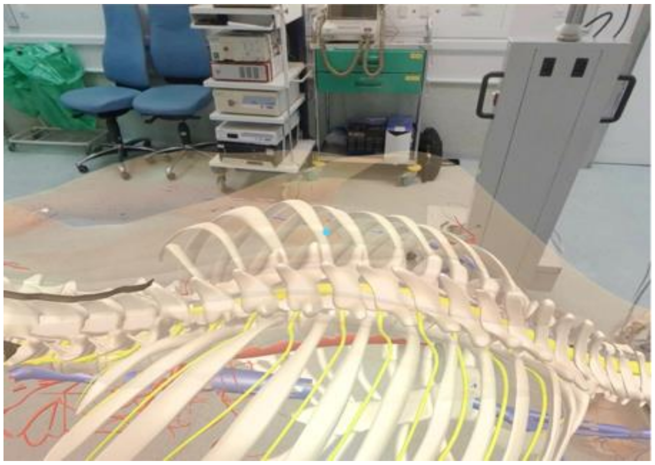

Figure 4: **3D model of human body used for simulation, based on P1 3D Anatomy V6/2015 anatomical models**

We have also included a spherical image of an operating room at the University Clinic Hospital of Salamanca (Fig. 4). The aim is to provide users with the most realistic experience possible, giving the sensation of being in a real operating room.

The programming language used for the implementation of the system has been C #. The code has been organized following the design pattern MVC (Model View Controller) [19], by which we have organized the different scripts in which the source code is divided into three large groups (see Fig. 5). The first one, the Model, contains all the scripts that store information and give access to it. In this case, it has not been necessary to use database, since all data are static and not too heavy. Text, audio, images and videos have been used, so these scripts also provide access to this multimedia content, necessary to contribute or complement the medical explanations offered by the system.

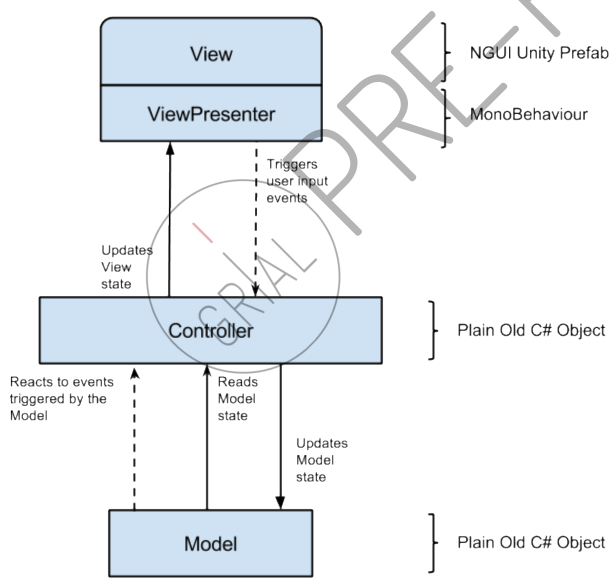

Figure 5: **MVC diagram that shows how the different modules of this pattern interact in Unity3D**

On the other hand, we have the Vista, which contains the scripts in charge of displaying the graphical elements on screen to the user.

2.2 Medical Procedure

All the steps of a fluoroscopic guided lumbar transpedicular fixationare described below [20]:

1) Under general anesthesia, with the patient in prone position on radiolucent sled, a cutaneous incision was made with a scalpel in the posterior midline lumbar centered on the area to be intervened.

2) Hemostasia with bipolar coagulation in case a vessel bleeds.
3) Placement and opening of autostatic separator.
4) Incision with electro-systolic in the midline by inserting the posterior paraespinal musculature on one side first, and then, the other side after step 5), exposing spinal processes, laminae and articular processes to its junction area with the beginning of the Transverse processes, assisted by a periostotom for muscle separation. With the left hand is held in muscle disinserted with the periostotom and continues to gradually deepen the muscle with the electro-systolic. It may be necessary to repeat step 2 at some point in time. It is interesting to leave the exposed bone without any muscle and without removing the supraspinatus and interspinous ligaments.
5) Separating the muscle laterally with the periostotome subject with the left hand, with the aid of a dissecting clamp, gauze or a compress is introduced, and with another periostotom the gauze or compress is progressed in the new cavity generated between muscle and bone. They make hemostasia and help muscle to detachment.
6) Steps 4 and 5 on the other side.
7) Remove with a clamp the gauze or compresses checking that they are outside all that have been introduced previously.
8) Insert of McCullock or similar type automatic separator and opening of the same.
9) At a hypothetical point between the joint and the transverse, a punch is introduced.
10) In pure Rx AP projection, with a single line without unfolding in the upper plate of the vertebra to be instrumented, and with the line of spines centered in the middle line, we must verify that the tip of the punch is, if it is on the side Left, in a position adjacent to the pedicular contour in a hypothetical time zone between 9 and 11 and if it is on the right side between 1 and 3. If it is not in the right place corrects until it is achieved.
11) After removing the punch, at the point of withdrawal of the punch, with a curved countersink, the pedicle is channeled by making the appropriate wrist twists to advance through the spongy pedicle until, without exceeding the pedicle contour with the tip of the countersink, in the pure AP projection we believe to have reached the vertebral body. It may be necessary at some point to draw blood from the surgical bed with a vacuum cleaner, for example when removing the punch, before inserting the countersink.
12) The bow Rx is turned under the table and a pure lateral projection is obtained, if we have arrived with the countersink to the vertebral body the trajectory is safe and we have not violated the cortical of the pedicle. If we are not in vertebral body, we must return to the previous step until we get it.
13) The hob is removed and the hollow generated in the sponge is palpated in its entire length and in all its walls, with the tactful sensation that our instrument is all surrounded by bone and that the trajectory of the probe is the same as that of the countersink in the lateral projection. If that is the case, we carry on, if not, we should start over again.
14) The user mounts the screwdriver (or screw fastener) the requested screw (depending on the size of the pedicle and the vertebra, which can be measured previously by image studies, the most used are 6.5 mm Diameter by 40 or 45mm in length).
15) With the left hand, we remove the probe while at the same time with the right we introduce the screw. Inhale previously to have the pedicle access hole bleed, especially if there have been several attempts to channel. If the pedicle is worked properly, try only turning the screw without pushing it to follow the carved path and self-guiding without resistance. Periodic monitoring of radioscopy is necessary to verify that the trajectory is maintained and does not change during its advance.
16) When all the necessary screws are inserted, the tulips are oriented with the tulip guide and a bar is placed with the clip, taking into account that their ends must exceed at least 5mm the ends of the tulips. If the bar is pre-curved (generally lumbar bars are used), they have a longitudinal centerline in the concavity and must be kept in the sagittal plane without letting it rotate.
17) With the bar placed and held the left hand, the user gives us the closing cap mounted on its holder that screwed on the tulip until it closes and holds the bar.
18) Repeat step with each tulip.
19) Steps 16 to 18 are performed on the other side.
20) With the anti-torque device "in L" shape and the torque screwdriver in "T" shape, the final tightening is carried out in each stopper Then the separator is removed and closed by planes.

Although there are other steps that must follow depending on the evolution of surgery, the previous steps summarize the actions that must be performed in this procedure. However, in the virtual simulation developed we have selected only the main steps, with the aim of creating a more general-oriented experience, which does not have to have any kind of medical knowledge. The steps selected were as follows:

1) Use the punch or estefi´s ball to work the way for the screw through the pedicle.
2) Attach the screw to the screw locker (Fig. 6).

3) Fastening the screw through the path previously worked.
4) Release the screw, leaving the screw in the polyaxial position.
5) Repeat steps 1 to 4 for the different screws to be placed.
6) Capturing of the bar with the clip holder.
7) Fastening the bar onto the screws.
8) Attach the closure cap to the holder.
9) Fixing the plug on the screw to fix the rod.
10) Release the cap.
11) Use of the antitorque device to close the cap, making a pressure of 90 pounds to avoid the movement of the bar on the screw.

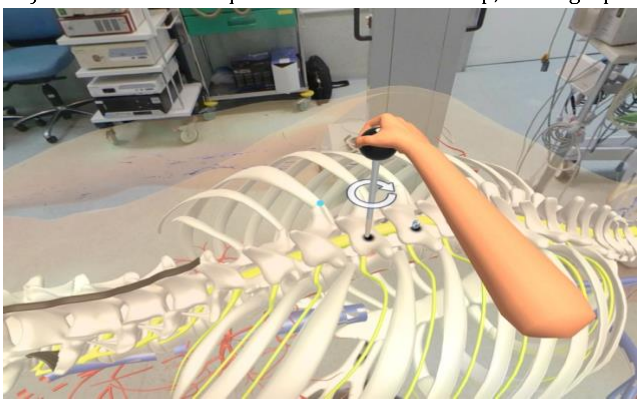

Figure 6: User using self-holding screw

After completing these steps, we will have the screws correctly inserted in the vertebrae, the bar on these three screws and the caps sealing the screws and fixing the bar to prevent their displacement (Fig. 7).

3 RESULTS

The obtained results with the development of this virtual interactive simulation system have been very satisfactory. On the one hand, it has been achieved that anyone is able to understand the operation of the system and use it perfectly after only a few minutes of execution. This is what in software engineering is known as usability (UNE-EN ISO 9241-9:2001), and basically measures how easy is to use the system. In this case, it was of great importance, since the system was not only oriented to doctors, who can devote a greater time to familiarize themselves with the environment, being a tool of work for them; the system is addressed for both medical professionals and for those who have no medical knowledge and, of course, no previous experience of using Virtual Reality systems.

On the other hand, the tool is capable of transmitting to the user what are the steps that must be taken in a lumbar transpedicular fixation procedure, which of course is the main objective. This has been achieved in three different ways:

1) Visualization by 3D animations of the tasks that must be carried out.
2) Videos of a real surgery for each step of the procedure.
3) Interactive simulation in which the user must test what he has learned by performing each step himself.

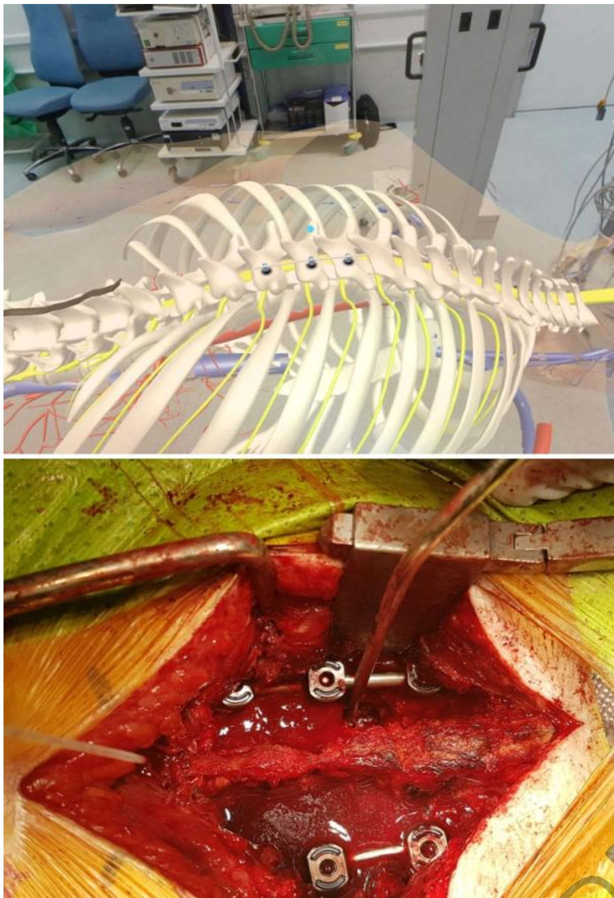

Figure 7: Virtual and real image of screws and bar in its final position

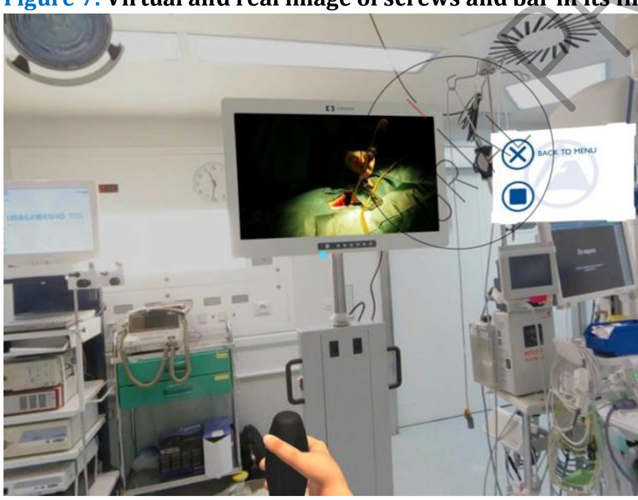

Figure 8: Visualizing video of real surgery in the monitor

In the first case, the system teaches the user what to remove the retrosomatic musculature, which includes the emigrated musculature and own musculature, each formed by its own muscles. Then these muscles are hidden and a video of a real surgery is shown for the user to see how the first step should be carried out: the use of the punch. The videos are projected on a television set inside the operating room, making the experience more realistic and attractive for the user (Fig. 8).

Once the video is visualized (there is an option to omit its reproduction), the user must carry out the action he has just seen, in this case perforating a vertebra using the punch. This drilling will be the one that will later be used to introduce the screw.

To perform each of the actions, you must move the knob by turning the wrist from side to side. This interaction of the user with the system through the movements of his own hands makes the experience more realistic, and therefore is more immersed in the simulation experience.

Once the slit is made, the user has a panel with the set of tools at his disposal, and should select the screw holder. At that time, you will be shown a video of how the screw should be mounted on the screw holder and how it should be used to attach the screw to the vertebra. Next, we will see a 3D animation of the assembly of the screw in the screw holder, and the user must then place it using the control again.

Once the screw is fixed, the system will emit a sound, which will be played each time a step is performed correctly. At that time, a video of how to remove the screw holder correctly, as well as a 3D animation of this same action will be shown.

When the user correctly positions the three screws, user must take the bar using the holder and place it on top of the screws. As always, before performing the action you will be able to see a video of that same step in a real operation.

Once the bar is placed, you must place each of the plugs to fix the bar correctly.

To conclude, a video of the device antitorque is shown. Interestingly, it exerts the appropriate pressure of the plugs on the bar to avoid its displacement.

4 DISCUSSIONS AND CONCLUSIONS

This system is a first step towards developing more complex and detailed simulations of surgeries. Nevertheless, it is a great example of how interactive simulations with Virtual Reality may help medical professionals to better understand the surgical processes, and serve as a tool to practice in a virtual environment and become familiar with the different tools used [4,14,15].

In addition, the system can be used for teaching purposes in academic settings, being a great learning tool for medical students.

One of the possible future lines of work for this system would be the improvement of each of the steps previously described, where for example the angle of entry of the punch or the screw holder is taken into account, so that if it is not inserted with the appropriate angle, the surgery cannot be successfully performed. For this, the user could be helped from the radiological images, which would show the angle of incidence of the punch/pedicle/screw.

It is concluded that the system is of great help to know the tools used in a surgery, as well as the most important steps of the procedure. It is also worth noting that medical professionals or students can perform the simulation as many times as they wish, unlike practices with real patients, which, for obvious reasons, can only be done a few times. Thanks to this unlimited repetition, it is much easier to automate all the steps that must be performed in a surgical procedure, as well as to remember the points of importance to take into account in each of them.

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