UTERHAP: Immersive virtual reality simulator for postpartum uterine involution using haptic devices

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Abstract
This work describes a virtual simulator integrating haptic devices with tactile feedback. The simulator allows users to perform the practice for palpation of uterine involution, where the user immerses in a virtual reality that brings closer to a real practice, the objective of this virtual environment is to speed up the learning process, since it provides practical notions to nursing students before having contact with real patients, highlighting that this simulator does not seek to replace real practice but rather to be an auxiliary tool.

Keywords:
Haptic Device; Virtual Reality Headset; Virtual Reality; Academic training; Virtual environment; Simulator; Mesh Deformer; Tactile Feedback.

1 Introduction
Uterine involution is a process that consists of the uterus returning to its usual size after childbirth, the evolution of the uterus through palpation is important to find symptoms that the mother may present, also the progress of the uterine inflammation can to give indications in case the placenta has not been completely extracted, this examination is essential during the time that the patient is under observation after delivery. The foregoing is valued by trained personnel, so practice is required, however, there are no simulators for palpation of uterine involution and nursing students must carry out these practices with real patients.

Therefore, it is important to integrate technology that allows nursing students to have tools that help to recreate real environments where these practices are carried out. With virtual reality, the user is immersed in an environment where their senses are intensified by showing a virtual doctor’s office through the Oculus Rift (vision) and interacting with virtual objects to reach them and feel their shape with the Touch 3D Stylus (tactile feedback). Another fundamental part is the deformation of the objects, by touching them, the user can perceive that he is interacting with a soft body (depth) and deduce how much force to apply to the haptic device. This virtual simulator with tactile feedback is a first approach for the students prior to the real practices, it was tested by teachers and the opinions were varied according to their experience, in general, they were interested and saw a future in virtual simulators.

2 Related Work
Below is a brief description of projects and research related to uterine involution simulators as well as the use of haptic devices.

The first work is the resectoscopy simulator is described in [1] for uterine resectoscopy in virtual reality, which by means of a mechanical uterus can be inserted the resectoscope and visualize on the computer screen how the examination progresses in the intrauterine environment.

Next in [2] which is a patent for a physical simulator for medical processes in the uterine area, this type of simulator is made of elastomeric material that simulates the postpartum abdominopelvic soft tissue very similar to the texture of the cavernous lining of the uterus. This allows simulating various techniques such as performing surgery, either for reasons unrelated to childbirth or merely obstetric and gynecological.

Later in [3] which the evaluation of the results of a study carried out with health personnel in Ecuador is discussed, where training was implemented for the placement of a device for hemostasis, to reduce uterine bleeding in postpartum patients.

After reviewing the related work, different opportunity areas were identified where virtual simulators can be developed:

In the previous works, the use of haptic devices is not presented, in such a way that the simulators are physical and can be a disadvantage since elastomeric materials might be damaged with the passage of time or improper use.

In simulators for uterine processes there is no specific model for palpation of uterine involution, it can be done, but the characteristics of the uterus are not adequate.

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According to the advice provided by the head of the Department of Obstetric Nursing Training at Escuela Superior de Enfermería y Obstetricia del Instituto Politécnico Nacional (ESEO - IPN), who mentions that the practice for palpation of uterine involution is carried out in the last semesters of the nursing career in person.

For the practice of palpation, one hand is required to exert force on the uterus and the other only to hold, so it was decided to use only a haptic device. In Figure 1 is shown the form of postpartum uterine palpation.
3.1 Simulador de la interacción humana-computadora

El simulador de palpación de la involución uterina está basado en el trabajo de [5] con algunas modificaciones, como se muestra en la Figura 2, que también utiliza dispositivos hapticos. Las flechas en el diagrama indican la comunicación entre los bloques, el usuario recibe el video output a través del Oculus y con el dispositivo haptico envía y recibe retroalimentación táctil. La operación de cada bloque está descrita a continuación.

3.1.1 Interfaz de Medios Virtuales (VRE)

La parte más importante es en la operación del simulador, donde el médico y el equipo médico son un medio visual para el usuario. Los modelos virtuales toman características físicas (masa, gravedad, detección de colisiones) para interactuar con ellos, para esto el administrador físico de Unity [6] fue utilizado. La ayuda de la física en Unity, es necesario identificar la posición de los objetos en el espacio.

Los modelos 3D rígidos de Los3D Systems OpenHaptics plugin obtenidos del AssetStore [7] también se utilizó, lo que permite efectos hapticos tales como fricción estática y dinámica, amortiguamiento, suavidad y poporcionar una interacción con objetos virtuales previamente configurados con características físicas, los objetos con estas propiedades: modelos uterina (véase Figura 3) considerando los estados del puerperio: inmediato (primer 24 h) y mediato (día 2 a 7), ya que a medida que van pasando los días, el tamaño del útero disminuye.

3.2 3D Models Behavior

La calidad de deformación de la malla se integra en 3D objetos virtuales, cuando dos objetos se colisionan y al menos uno tiene esta calidad de deformación, el objeto se deformará en sus mallas que después de un tiempo volverá a su forma original, esta propiedad se conoce como movimiento elástico, el objeto con esta calidad es el modelo abdomino-pélvico.

Para este bloque es necesaria la existencia de dos dispositivos hapticos (virtual y físico), cuando el usuario mueve el dispositivo físico en la pantalla se verá el dispositivo virtual moverse, lo mismo sucede cuando el usuario interactúa con objetos virtuales. Para este motivo, se diseñó un modelo de mano como un avatar del usuario (véase Figura 4), se configura como un controlador llamado grabber o manija y limitado en un espacio llamado hapticDevice, que es un cubo invisible para el usuario y solo en ese espacio funcionarán las propiedades hapticas. Estos últimos dos ajustes son de OpenHaptics plugin.

3.1.2 Representación Haptica

Aunque los procesos de simulación se realizan en el bloque VRE, la comunicación física entre el dispositivo haptico y el entorno virtual es importante, para este trabajo el software de desarrollo haptico [8], este software calcula la posición real del dispositivo haptico según los movimientos y fuerzas aplicados por el usuario, si se produce una colisión con objetos virtuales configurados en VRE, se obtiene retroalimentación haptica (fuerza), este bloque necesita frecuencia de procesamiento al menos de 1kHz.

3.1.3 Representación Visual

El motor gráfico Unity es responsable de recolectar todos los bibliotecas necesarias para mostrar el video output a la pantalla con el apoyo de OpenGL. Sin embargo, el principal producto de la simulación es el Oculus Rift, por lo que el software de Oculus es el que permite el soporte físico del dispositivo y el ordenador, para Unity, el XR.Plugin Management es obtenido en el administrador de paquetes que proporciona los scripts necesarios para configurar la cámara de realidad virtual que es la del Oculus. Luego el usuario puede elegir en que dispositivo desea ver el entorno virtual. La frecuencia de procesamiento está entre 30Hz y 60Hz.

3.2 3D Models Behavior

Como mencionado anteriormente, el simulador debe ser inmersivo, lo cual es por que el área abdomino-pélvica requiere un efecto de deformación cuando se toca la piel real, y luego se requiere más realismo para la simulación. Así, el modelo abdomino-pélvico fue diseñado independientemente de la figura femenina, de esta manera se puede agregar colider característico y deformador de malla, y la deformación se configura como se muestra en la Figura 5.
3.2.1 Mesh Deformation

The mesh deformation script was written to calculate the position of 3D model vertices with physics qualities, through mesh filter provided by the Unity physic engine to identify the initial position values which will be used later to return original form. Two forces are required for this script: applied force and the offset force to compensate the force with which the meshes are pushed radially or the inverse force applied with the user avatar in Figure 6 is shown the flow chart to mesh deformation.

![Mesh deformation flow chart](image)

**Figure 6. Mesh deformation flow chart.**

The vertices are pushed by the applied force; however, it is necessary to identify the speed and direction of that push. The applied force \( F \) becomes speed \( F_v \), this is where the inverse square law applies where the original force is divided by one plus the distance squared.

\[
F_v = \frac{F}{1 + d^2}
\]

This guarantees that the force is maximum when the distance is zero \( d \), so, the greater the distance, the lower the speed.

Regarding the direction, it is enough to normalize the vector of the applied force. Although the vertices are already moving, their position and normals must be recalculated as fast as processing frequency between 2kHz to 5kHz, this maintains the original shape of the mesh. This is done by applying elastic force or springs to move the vertices in an inverse way but with a different speed from that applied. This speed is calculated by the difference of the initial thrust speed and the product of the displacement, spring force and time. Every time a vertex moves in reverse, the speed decreases.

Now, it is possible to move the vertices and return them to their original position, however, due to the nature of the position calculation, it tends to repeat itself infinitely. To solve this oscillation, the application of damping is used, with which the speed of the displacement is further decreased over time, thus returning the vertices to their original position.

When moving the vertices, it is assumed that the scale of the 3D object changes, the object might grow or becomes small, to compensate for this action it is first necessary to identify the original scale of the object and then compare it with the scale when the vertices have displaced. Then, the scale is readjusted so as not to lose its uniformity, this is called meshDeformation.

3.2.2 Mesh Deformer

To perform the deformation in the abdominopelvic area at the contact point of the user avatar or meshDeformer, the mesh deformer script was written (see Figure 7), it is necessary to obtain the coordinates of that contact point. First, the position of the user avatar is calculated, the Haptic Interaction Point (HIP) was located at the tip of the index and middle fingers, this sphere is considered the origin for the projection of a shock beam and the direction used is the inverted Y axis. Then, a ray that is not visible to the user comes out of the user avatar, in such a way that when making contact with the area to be deformed, the coordinates of the point where the ray collided with the mesh collider are calculated. At that point the deformation force is applied to move the vertices, an action performed by the mesh deformation script.

![Mesh deformer flow chart](image)

**Figure 7. Mesh deformer flow chart.**

4 Preliminary Results

To carry out the preliminary tests, 5 volunteers attended the presentation of the simulator for palpation of uterine involution. All the participants are nurses and teachers at ESEO - IPN, aged between 33 and 50 years old, experts in uterine palpation during the puerperium. For these tests, the equipment used was a laptop ASUS with intel i7-9750H @ 2.50 GHZ processor, 16 Gb. RAM, Nvidia GeForce RTX 2060 graphic card, 1 HDMI port and 4 USB 3.0 ports. Also, one Oculus Rift headset and the haptic device Touch 3D Stylus were used.

For practice, the user must be seated in front of the computer, put on the Oculus Rift and hold the Touch 3D Stylus with the dominant hand, before starting the simulation (see Figure 8). User was instructed about the actions that could perform within the virtual environment: observe the doctor’s office by moving the head, with the haptic device touching the abdominopelvic area and when applying pressure could feel different stiffness depending on the phase of the puerperium.

The default setting selects the uterus in the immediate puerperium, with the uterus being the largest. Then the user can select another uterus from those available. At the end of the practice, a brief questionnaire was made to the participants where the answer could be agree, indifferent or disagree. Although the participants shared their experience through a comparison of real practice with this simulation. The results shown in the Figure 9 were obtained.
It is observed that 95% agree that the feedback force is similar to a real practice. 80% agree that when interacting with objects their shape and texture can be felt. 70% agree with the perception of depth when touching the skin and seeing how it deforms. 50% were able to identify the postpartum phase by palpating the uterus with the haptic device. And 100% of the users experienced the immersion of being inside a virtual medical environment. 

**Figure 9. Questionnaire results made to the participants at the end of the tests.**

**5 Conclusions and Future Work**

In both medicine and engineering, it is important to have tools that help students acquire the necessary skills. In this case, the use of haptic devices with tactile feedback and a virtual reality viewer immerses the user in a virtual environment to perform virtual practices that are reliable to what would be done in a real practice.

So, the contribution of this work is to simulate the palpation of uterine involution using virtual models with tactile properties that can be felt with a haptic device and the recreation of a virtual medical environment with elements that allow the user to immerse themselves in that with a headset. At the same time, the practitioner is made aware of how this practice should be carried out without disturbing or damaging real patients. Even perform this practice at any time and as many times as necessary regardless of the number of people who are observing the uterine exploration process. The work developed stands out because there was no simulator of this type, however, areas of opportunity are identified that can allow improvements to this work.

Graphics improvement. To optimize the ratio of graphics quality and simulator performance.

Improved touch parameters. Perform more tests with nurses to further fine-tune the haptic characteristics.

Integration of any haptic device. The simulator supports 3D Systems OpenHaptics compatible devices but others could be added.

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**7 References**


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