Hand Tracking and Haptic-Based Jugular Neonate Central Venous Access Procedure

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Abstract. Medical simulators are important because they provide means to teach, learn, train, practice and develop skills necessary during medical practice. Simulation also allows exposing trainees to scenarios not possible during training, thus covering a wide range of life-like situations. Although widely used, simulation still faces challenges due to the high costs associated with the simulation equipment. Current advances in computer graphics and user interfaces provide affordable tools that allow exploring solutions in different medical fields. In this paper, we focus on the jugular central venous access performed on neonates, a procedure commonly practice to save lives through drug, nutrients and other medication administration. Simulation to practice this procedure is scarce and focused on adult simulation, yielding to transfer of knowledge to treat a neonate. Our approach focuses on developing a simulation prototype covering the preparation steps and execution of the procedure. To provide natural interactions, we integrated hand motion capture with haptics within a virtual environment representing the operation room. To study the prototype's user experience we asked 12 participants from last year of medical school to use the prototype.

Keywords: Simulator · Central venous access · Haptics · Neonate · Tracking · Virtual reality

1 Introduction

The central venous access (CVA) is an invasive medical procedure that demands great knowledge and skill during its execution. The skills are developed through training and refined during medical practice. The CVA is relevant for administering medication and nutrients directly into the circulatory system, in the case of neonatal patients; transfer of knowledge takes place as the training is performed on adult simulators or patients [27]. CVA is a feature available on some adult and pediatrics manikins, where trainees are able to measure vital signs, perform needle insertion and administration of medications, while the instructor controls and monitors the patient behavior to guarantee that the procedure is performed with proficiency [22]. Provided the scarce solution on neonatal CVA,

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we focus our work on the jugular access because it allows better medication administration [4]. Transfer of knowledge presents challenges on its own as the anatomy of the neonate differs from the adult (e.g., skin is thinner and organs are closer) [28].

VR medical training research and development has resulted in solutions such as, surgeon virtual training systems [14,34], navigation and 3D visualization of anatomic models [11], tools for image manipulation by hands tracking [29,31], surgeries immersion systems [10,20]. All of these provide alternative and complementary training tools that allow minimizing the probability of bad praxis or iatrogenesis. All these systems simulate the anatomic and physiologic characteristics of a patient with various levels of fidelity, determined by the quality, precision and realism.

Specifically, CVA adult simulation includes features that provide visual, physical and mechanical biological-like tissues. Many of surgical simulators [13,25,39], use different models including non linear elasticity, fluid simulation and finite elements analysis, allowing them to represent tissue displacements and deformations, making them more similar to real procedures. To provide interactions with touch feedback, some simulators include haptics devices to improve the user experience with the human anatomy [23,24,38]. Often, as an affordable approach, multimedia tools can be found focusing on learning the procedure in newborns [8], applications for the needle insertion in the virtual newborn jugular practice [37], systems that integrate physical models with virtual environments [17,18], and ultrasound simulation [1].

Currently, virtual reality in medical simulation is still a demanding field due to its impacts in health professions education [3]. From the literature review, neonatal simulation is still on its infancy, providing grounds to research, and explore solutions to provide complementary training tools to address specific skills not relying on transfer of knowledge from current adult systems to the newborn. The goal of this work is develop a virtual simulator prototype to practice the jugular CVA using virtual reality as a mean to deliver an engaging realistic experience to the user. The paper is organized as follows, Sect. 1 describes previous and related Works, Sect. 2 presents proposed methodology and developed prototype, Sect. 3 described the user experience, the results are described in the Sect. 4, and Sect. 5 concludes the paper outlining future work.

2 CVA Simulator Development

From the characterization of real CVA procedure [15], three key elements were established to develop the simulator: interaction with a neonate patient including realism and suitable natural interactions using sight and touch senses, prior practicing with surgical tools and procedure steps.

In order to achieve these elements, we integrated virtual reality hardware (e.g., a Head Mounted Display, hand tracking, and a haptic device), to engage the user. In the application, we recreated an operation room using the Unity 3D 5.1.3

game engine [36] using 3D models for representing the required surgical tools [5,7,32,35] allowing the interaction between user with the patient and instruments. The virtual system is comprised of three modules including, a practice module, an evaluation module and an information module, as presented in Fig. 1. Our approach consisted of characterizing the CVA procedure to identify the systems input and outputs along with the required subsystems.

In the practice module, the user can manipulate all the tools with his/her own hands using a hand tracking system, increasing the dexterity and enhancing skills in instrument handling. In the evaluation module, the user performs the procedure as follows: (i) cleanliness of the hands (I know there is a medical name for this); (ii) wear the gloves; (iii) patient asepsis; (iv) needle insertion; (v) placing of the transparent bandage; and finally, a radiography analysis to ensure that the catheter was placed appropriately.

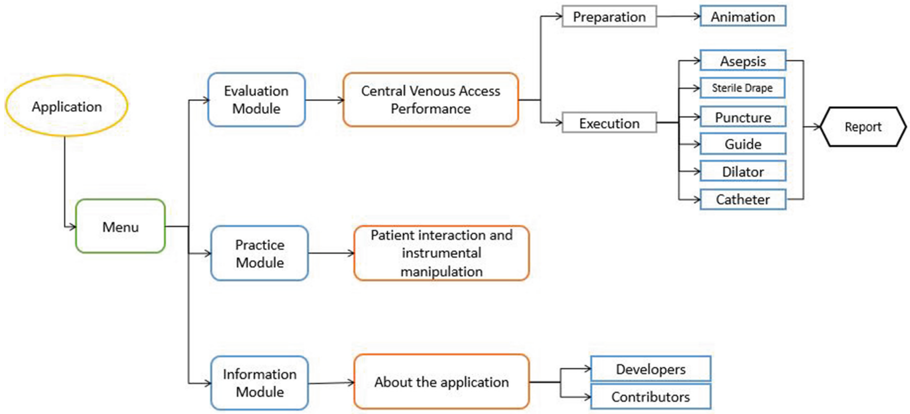

Fig. 1. System description

2.1 System Architecture

The system is composed by a haptic and visual system for a complete virtual reality experience. For the visual feedback, we decided to use a head mounted display to provide stereoscopic immersion. For this purpose we chose the Oculus Rift DK 2[21] that offers the user a wide vision field of 100 degrees diagonal FOV and 90 degrees horizontal FOV, characteristics sufficient for our scenario (neonates neck and surrounding regions). To provide natural user interactions, we decided to use the Leap Motion hand tracker [19], which allows the user to interact with the different objects of the scene, and also a Phantom Omni [12] haptic device that provides tactile feedback relevant to the CVA (Fig. 2).

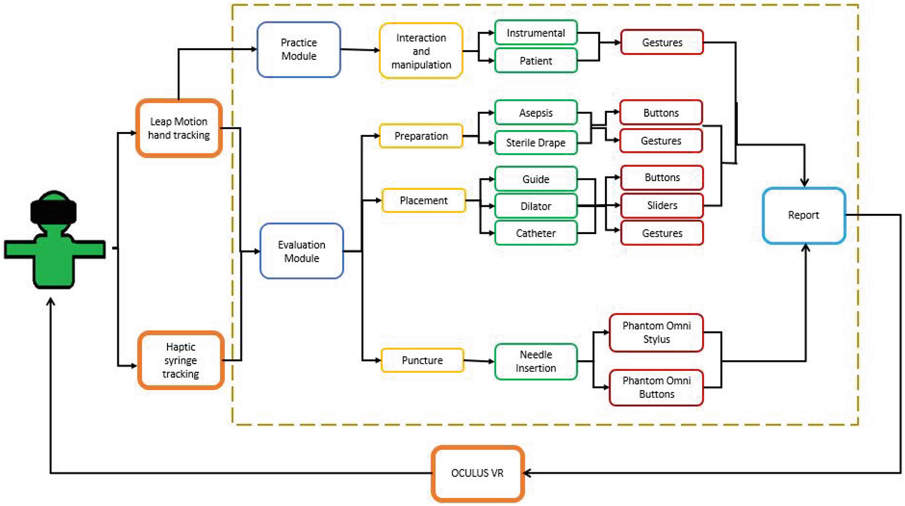

Fig. 2. System architecture

2.2 CVA Procedure Setup

The application starts with a menu allowing user to access the different modules and configure sound and language (english or spanish). When the trainee starts the practice the procedure begins requiring the user to perform the following tasks associated with the preparation for the procedure: i) hand washing; ii) glove wearing. To accomplish this tasks, we used Leap Motion features to track the movements of user's hands and wrists. Figure 3 depicts the tasks.

Fig. 3. Hand washing and gloves placement

The next step of the procedure is to prepare all equipment and instrumentation (shown in Fig. 8). To accomplish this task, our system uses hand tracking so the user can reach them in a natural manner (Fig. 4).

Then, the user performs the patient asepsis (Fig. 5a), for this task, we used the Leap Motion to take advantage of hand tracking to make interactions life-like.

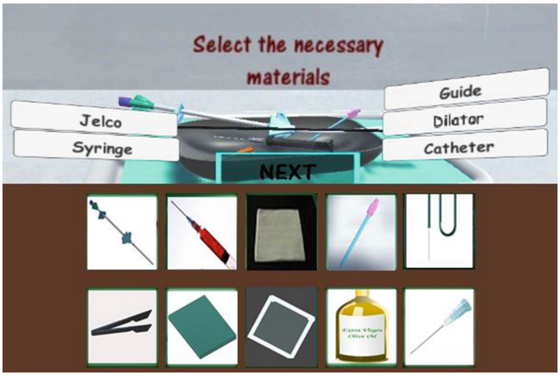

Fig. 4. Instrument selection [6,9,26,33]

When the user pinches the index and thumb, a gauze immediately appears so it can clean the patients areas of interest. As the user performs this action, a progress bar provides visual feedback on the task completion. Once finished, the user is required to place the sterile drapes as depicted on Fig. 5b.

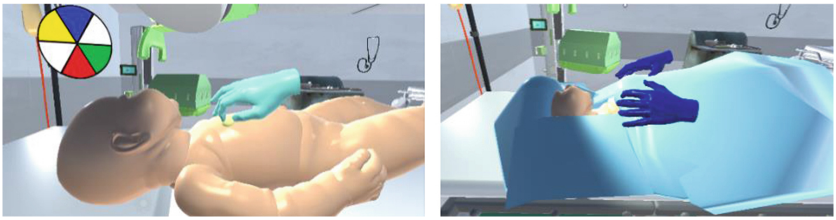

Fig. 5. (a) Patient asepsis and (b) sterile drapes placement

The next step is the catheter placement. This part is divided into four subsystems consisting on: (i) the needle insertion; (ii) the guide insertion; (iii) the use of the dilator; and finally, (iv) the catheter insertion. The needle insertion subsystem receives information from the Phantom Omni haptic device tracking yaw, pitch and roll and provides force feedback when the needle is inserted. Haptics interactions were implemented in Unity using Kirurobos C# wrapper for Phantom Omni [16]. To guarantee proper jugular vein puncture, the anatomical structures involved in the procedure were considered and so the organs, tissue and bone provide collision feedback. Even though the Digimation 3D models used (rib cage, heart, lungs, clavicle and blood vessels) [7] aren't anatomically correct, they provided all the information of its location and size. The perception of its physical properties are modeled by linear elasticity [38] (Fig. 6).

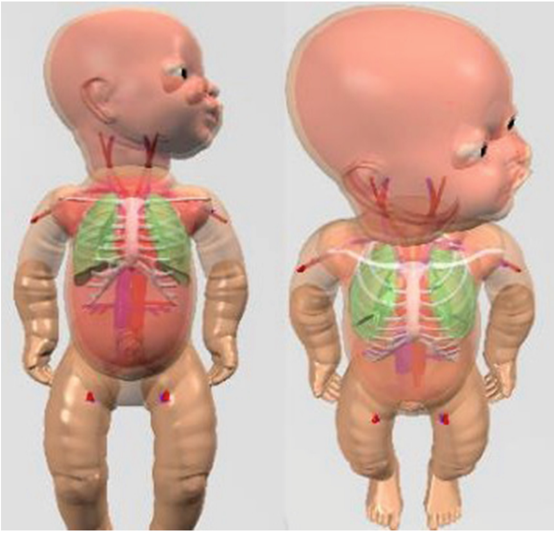

Fig. 6. 3D Models of the anatomical structures involved in the CVA procedure

When the needle touches the jugular vein, a stream of blood starts to enter the syringe as shown in Fig. 7a. When the user presses the button with the newborns image, the internal anatomical structures become visible to aid the insertion process.

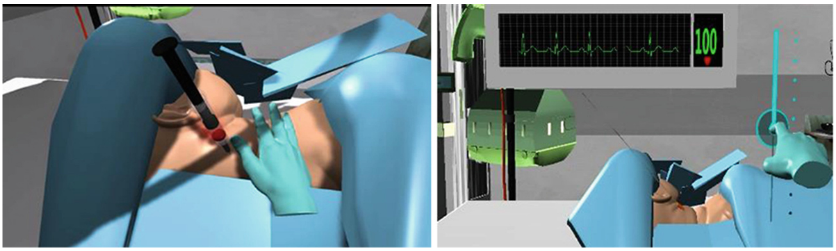

Fig. 7. (a) Needle insertion subsystem and (b) guide insertion subsystem

The guide insertion subsystem receives information from the Leap Motion device, the user must manipulate a slider to introduce the guide inside the jelco, as it is presented in Fig. 7b. The subsystem has an ECG, developed by Mike Austin, to control the patient cardiac frequency [2]. When the guide reaches the heart, an arrhythmia occurs, in this moment the user must back the guide until it stops. As soon as the guide is inserted, it is necessary to withdraw the jelco, for which, the user must to perform the swipe gesture with either hand.

Another subsystem that receives information from the Leap Motion, is the dilator (shown in Fig. 8a). The user manipulates the instrument through a circle gesture with the right hand, and with the left hand, by a swipe gesture, she or he removes the dilator.

To place the catheter, the user uses the same dynamics as with the guide, as it appears in Fig. 8b. Once properly positioned catheter, the guide is removed with the swipe gesture.

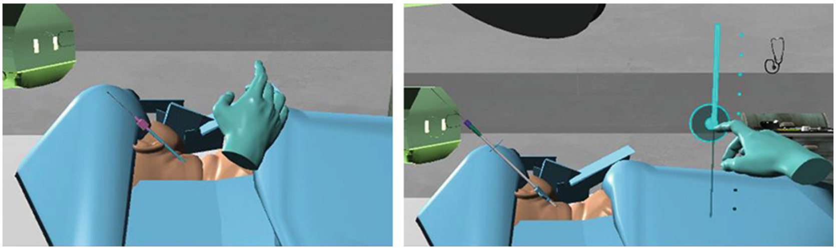

Fig. 8. (a) Dilator manipulation and (b) catheter insertion subsystem

Once completed the catheter placement, we proceed to place the transparent bandage to secure the catheter, as presented in Fig. 9a. Finally, the user takes a radiography to verify that the catheter placement as shown in Fig. 9b.

Fig. 9. (a) Final position of the catheter and fixation with transparent bandage and (b) radiography room (X-ray image [30])

3 User Experience

In order to analyze user perception with the developed tool, we carried out a series of test, which allowed us to verify if it contributes or not to learning the CVA procedure.

For the user experience evaluation, we use two computers with Windows 7 Enterprise 64-bit operating system, Intel Xeon processor, 8GB of RAM, NVidia

Quadro 4000 graphics card, IEEE-1394 and FireWire PCI Card. Also, we use two Oculus Rift, two Leap Motion, two Phantom Omni devices, and a pair of earphones, Fig. 10 shows one of the participants testing the system.

Fig. 10. User experience evaluation

At the time of evaluation, the first thing we did was to inform participants about the test, giving them a brief introduction to the game. Then, the experimenter indicated them to sit down, and put on the Oculus Rift and the headphones. At the puncture time, the experimenter gave participants the Phantom Omni stylus. Throughout the test, the application indicates the user the necessary instructions that this one has to perform. At the end of the test, we thanked the users for their participation, and asked them to answer an online survey in order to know their opinion about the application and their satisfaction.

4 Results

To analyze user experience using our solution, we gathered 12 participants from last year of medicine undergraduate program who did not have prior knowledge of the procedure. Once gathered the simulator was explained and participants were asked to used it navigating and exploring all features. The activity lasted 15 min per user and from the questionnaire and observation we highlight the following considerations:

- **Usability.** In this regard, we evaluated how easily turned out to be to the user to interact with the virtual patient (Fig. 11a). Most of the evaluated population agreed that it is normal, another part said that it was easy or that they needed practice, and a small minority answered that it was difficult.

- **User Experience.** In this part, we evaluate the degree of user satisfaction when our system was used, 100 % of the evaluated population enjoyed the application.
- **Immersion.** Regarding the immersion, most of the evaluated population experienced a presence sense in the implemented operations room, ensuring that the use of virtual reality devices contributed to this satisfactorily (Fig. 11b). Most of respondents rated as good the feedback force, and the other part rated this as regular.
- **Environment.** We ask the users to rate the implemented environment (Fig. 11c), most of them assigned a score of five (excellent), and the other part of them qualified it with four or three, none rated it with zero (deficient). Regarding the realism, many people considered it good.

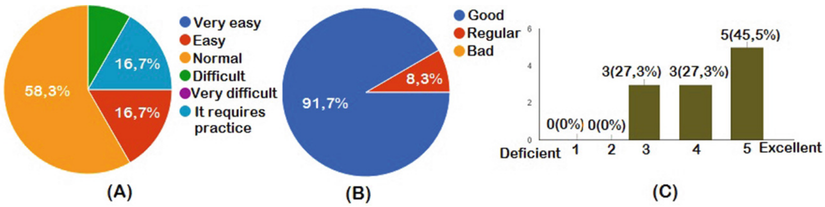

Fig. 11. Evaluation results: (a) Usability, (b) Immersion, (c) Environment

As to whether the application was useful in terms of learning, practice, and training in this area, big part of the study population (91.7 %) answered affirmatively. This is evident in that many of the users understood better the CVA procedure on having used our tool.

5 Conclusions and Future Work

According to user experience evaluation and analysis of results, we realized that the developed tool is helpful in the education and training of CVA, further by including various virtual reality devices, the user feels more immersed in the experience, which makes our application more appealing and entertaining, As future work, we will improve the force feedback including the modeling of vein rupture event, and we will implement a scoring system that will give to the user a qualification based on his/her performance.

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