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INTEGRATION OF A HAPTIC GLOVE IN A VIRTUAL REALITY-BASED ENVIRONMENT FOR MEDICAL TRAINING AND PROCEDURES

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Abstract: *During continuous development, Virtual Reality (VR) technologies propose new challenges regarding partial or total immersion in a simulated environment using a computer and a Head Mounted Device (HMD). Thus, tools were created to offer new means of interacting with the surrounding environment but with the advantage of preventing harmful actions, thus making them perfect and extremely versatile tools for training. Knowledge acquired during the experiments and simulations conducted by the authors in previous research, based upon developing a sensory glove, proves that it can be applied in medical issues, surgeries and even in the recovery of patients. The purpose of this paper is to integrate a sensory glove with haptic feedback into a virtual environment, which a person can use to experiment a new way of learning in a real and possible situation without taking any risks. The novelty consists in the development of devices that facilitate the training through Virtual Reality applications in a cost-efficient manner.*

Key words: *Haptic glove, Virtual Reality, feedback, immersive learning.*

1. INTRODUCTION

Touching is one of the 5 senses that, for us humans, represents something trivial, but still very important and indispensable, especially in moments when it completely replaces another sense. A real example, but unfortunately sad, is that of blind people, who, forced by circumstances, are constrained to “see by touch”. Through the visual sense, a person can realize the shape of an object; instead, blind people can visualize its shape by touching and building the shape of that object at a mental level. Also, aided by muscles, the sense of touch allows a more complex interaction with a particular object [1].

Everything related to touch or contact between the human body and another object is called haptic. This term is not a new one, but one that comes from the time of the ancient Greeks which referred to the ability to make contact. In order to simulate touch, man has developed haptic technology, a type of mechanical simulation that has the potential to reproduce certain stimuli to a user. This technology has become very widespread, becoming a basic functionality for phones, console controllers, detection equipment. The potential offered by this technology is quite consistent considering that it can be easily integrated into other technologies related to Virtual Reality (VR), augmented reality, automotive, industry, research, and even in the medical field [2].

The authors aim to integrate a sensory glove with haptic feedback in a Virtual Reality environment in order to facilitate the staffs’, students’ training, and even patients’ recovery, in a more cost-efficient manner, these aspects being detailed in the following paragraphs.

2. STATE OF THE ART

In E. Ganea’s work [3], we find as an example of a haptic device the “Omni Phantom interface (Geomagic Touch)” that benefits from haptic feedback through the interaction with virtual instruments and virtual organs. Using this haptic interface, together with the Simulation

Open-Framework Architecture (SOFA) work environment, we find experiments and applications for different medical situations simulated in the virtual environment. The simulation of the medical act with force feedback makes it possible to feel the collision with the virtual organs in order to ensure adequate training for future medics.

According to F. Manta [4], collision plays an important role in medical applications, and can be addressed in various case studies, analyzes and operating environments even in Virtual Reality.

Currently, we can identify different systems that come in aid of the medical field through devices equipped with sensors and state-of-the-art technologies, for simulating or integrating subjects in Virtual Reality in order to train, learn, and even experience various scenarios. Thus, we find Virtual Reality systems and equipment such as gloves and Head Mounted Devices that offer haptic feedback, but at a fairly high cost.

The strong advancement of state-of-the-art development in recent years has become possible thanks to the parallel advent of technical methods used to design technological structures. The previous work of the authors, *"Virtual simulation for a sensory glove with haptic feedback"*, highlights experiments of a sensory glove device able to transmit input to a user with the purpose to assist effective learning [5].

Three subsystems are included by the virtual glove: "Hand and finger positioning subsystem", "Vibration micromotor command and control subsystem", and "Glove-computer communication subsystem". By creating such an interface suitable for Virtual Reality, as a training or medical equipment, it is desired to take advantage to turn to account its potential for preventing harmful actions.

While the previous concept was designed and developed only for proving that a low-cost design can be very effective when integrated with a virtual environment, just as the conducted simulations have resulted, the current work is about pushing the limits further and obtaining a suitable system for different real scenarios that will allow the user to interact without the risk of altering or damaging any of the equipment or the object upon he is working on.

3. HAPTIC TECHNOLOGY

As haptics is based on receiving feedback from the user, different methods were approached to implement this technology, such as force, pressure, or resistance. Because of that, devices that were developed are using hydraulics, pneumatics, or electric actuators.

The most common way that we experienced haptic technology until now is through the help of mobile devices. Latest software updates turned a vibration micromotor into a much more complex device, converting its basic functionality into haptic response. This is how a simple vibration micromotor can provide feedback when typing a message, when an alert comes up and even when a certain part of the touch screen, also, it can let us know there are notifications when the cell phone is picked up from the table even if it is locked. Thus, haptic feedback became a part of our daily life without knowing it. Over time, a multitude of devices, equipment, and systems have been developed implementing haptic feedback technology [6].

Haptic systems represent the blending between human and machine. Therefore, haptic feedback can take place when, according to human movement, the machine reacts and produces stimuli for the human to feel.

Brain controls and conducts movements and receives inputs from the nervous system, thus describing the interaction between human and machine (see Figure 1 a, b).

a) b)

Fig. 1 Haptic devices: a) Quanser HD2High Definition Haptic Device; b) Geomagic Touch X Haptic Device

A system that provides haptic responses has to contain hardware for the human to interact with, software, and a type of actuators. The device must have predefined degrees of freedom resulting in a number of transitions and rotations that can be applied to it. The hardware component allows the gathering of inputs and provides outputs according to the software that controls it. Also, another important aspect is the actuator which actually exerts the force that the user feels [7]. Here, a compromise has to be made between the size of the actuator and the power or fidelity that it can provide. Furthermore, for this paper, vibration micromotors model 1027 have been considered to act as actuators.

This paper intends to develop and experiment some applications that can test the inputs of the control circuit for the haptic micromotors, and implement a proposed system that is presented in Figure 2 concept diagram, by integrating a haptic glove in Virtual Reality.

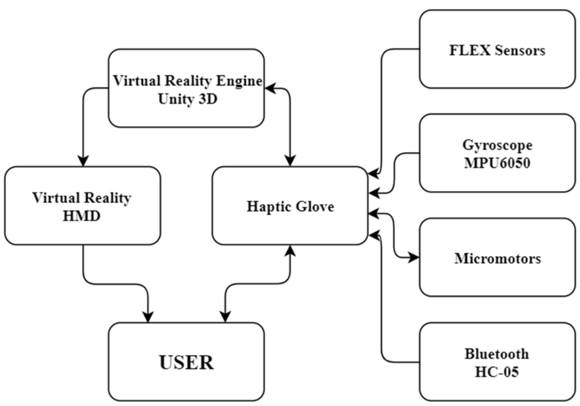

Fig. 2 Concept diagram of the system

This architecture shows how the modules interconnect with each other and how the user interacts with the virtual reality environment. This is the concept approach for the user to experiment haptic feedback. The haptic glove communicates with the virtual reality Head Mounted Device (HMD) through a Bluetooth protocol. Both devices are connected to a computer which integrates the haptic glove and the Head Mounted Device in the same environment.

4. APPLICATION DEVELOPMENT

In order to successfully develop and test the concept proposed by this paper, we chose to integrate the glove with haptic feedback (see Figure 3) in a virtual environment running on the Unity software platform.

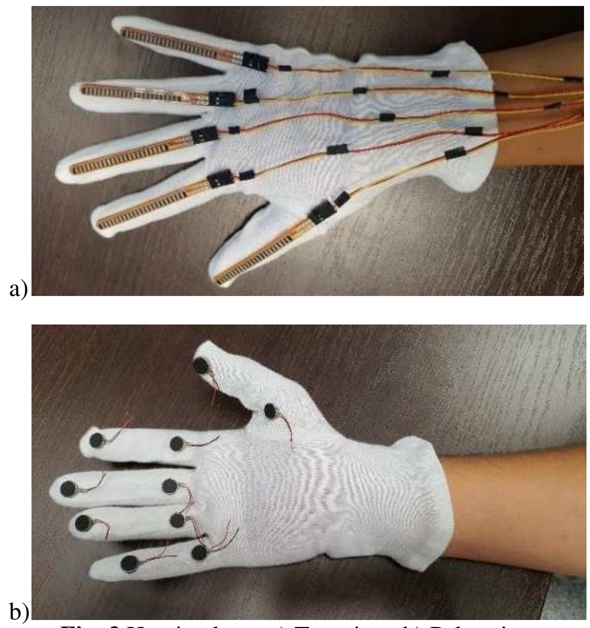

Fig. 3 Haptic glove: a) Top view; b) Palm view

The application developed in the Unity framework is based on creating a 3D model of a human hand, to which a system of axes will be attached to each joint, following that the movements of the user's glove will have an effect on the 3D model. Figure 4 shows the initial prototype of the 3D model on which a series of basic tests were run to observe the correct functionality of the system and the traceability of the signals from the moment they were recorded by the sensor, until they manage to adjust the position of certain elements of the 3D model, also called *GameObject.*

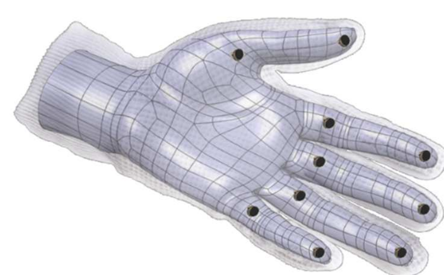

Fig. 4 Initial prototype of the 3D model implemented in Unity

4.1 Basic component testing

The communication between the glove and Unity is wireless, provided by the Bluetooth protocol. Thus, two Bluetooth modules were used to facilitate the user's movements while allowing a more complex set of movements. The two modules work as master-slaves in the idea that the haptic glove (slave) is responsible with reading the data provided by the sensors and passing them to the module that acts as the master, being also the one who makes the query for the data.

Also, the module that acts as master is connected to a CH340 module to convert the received data into USB protocol and to transmit it to the computer port.

In order to benefit from this data and use it to control the hand model in Unity, a communication channel must be provided by the USB port where the relevant data will be received. The opening of this communication path is done through Unity, because it is able to run scripts written in the C# programming language. That can give life to certain objects and can animate them. Also, through the same type of scripts, the command part that will reach the micromotors of the glove will be made.

Once the communication channel is opened, the data recorded and transmitted by the glove can be viewed and retrieved via the *Update()* method. The example of a communication message from the oscilloscope is shown below in Figure 5.

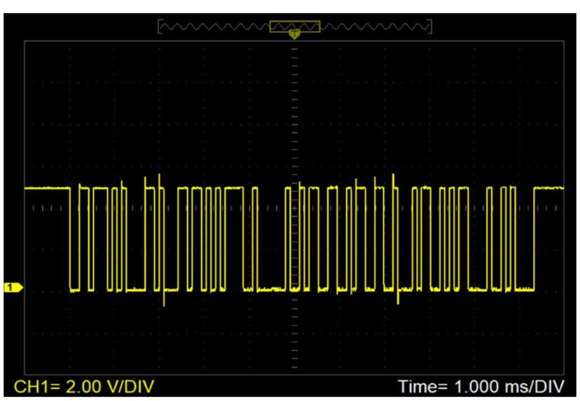

Fig. 5 A sample of message representing the communication between the haptic glove and computer

As the first test to be run in order to demonstrate the functionality of the whole system, it was desired to move one finger to observe the behavior of the 3D model and to see what adjustments are required for the model to behave similarly to the reality.

The result can be seen in Figure 6, representing at the same time a comparison between the real movement and the virtual movement also read through the oscilloscope and the serial plotter integrated in the Arduino programming environment.

a)

b)

c)

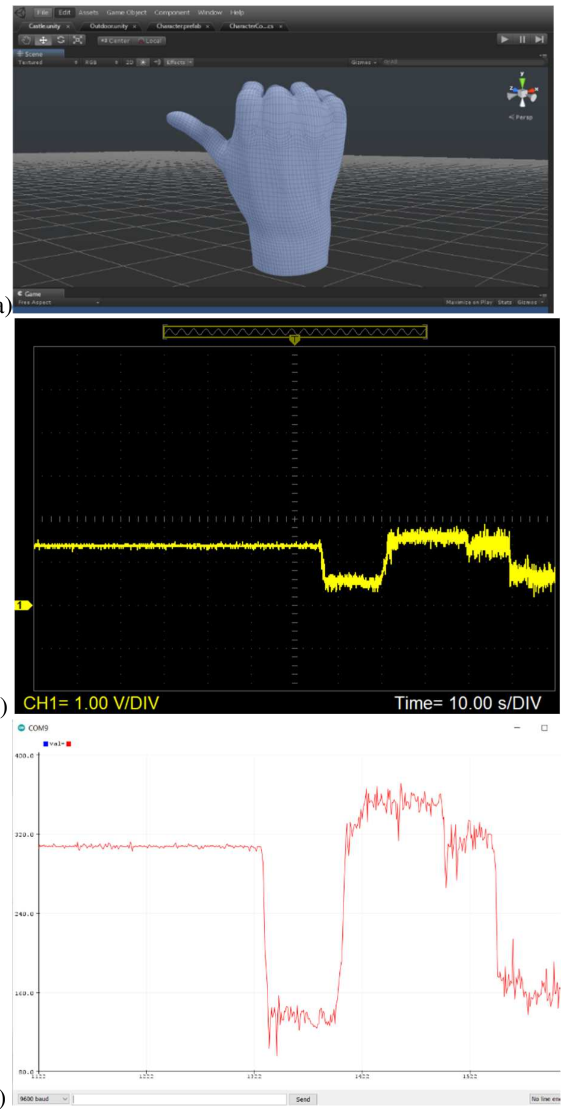

Fig. 6 Comparison between: a) virtual model response to the glove's movement; b) flex sensor's response to the movement of a finger – signal captured by oscilloscope; c) flex sensor's response to the movement of a finger – signal captured from Arduino IDE's serial plotter

Micromotor testing was performed by continuous control using a 1kHz PWM signal, with a duty cycle of 50% (see Figure 7).

For the first test, the values were hardcoded and the approach to trigger the execution of the command was to send a character through the communication channel that has already been established, taking care that, at the other end, the glove executes the command referred by the sent character.

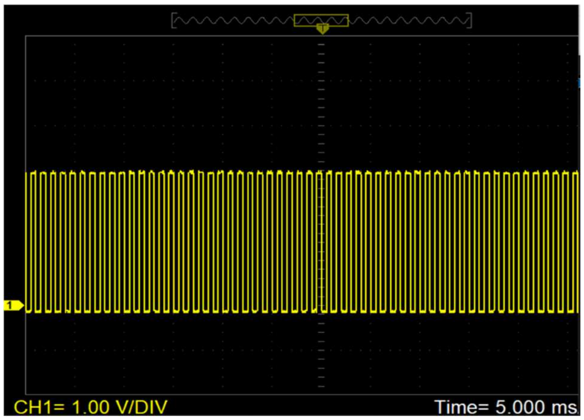

Fig. 7 Experimental continuous command signal – 1 kHz PWM with 50% duty cycle

The result of this test was that once the command was received by the glove, the micromotor vibrated in correspondence with the command received, thus proving the operation of a rudimentary feedback.

The second test run had the purpose of dynamically modifying the duty cycle of the PWM signal while the command was sent to the micromotor.

In order to be able to perform these tests, the implementation of a method which will be called with the parameters in which the first one represents the micromotor's identifier and the second one the applied PWM signal was considered.

The result of the second test represented a dynamic control of the micromotor, managing to reproduce quite well both a stronger and a weaker feedback (see Figure 8).

Hand movements are recorded using an MPU 6050 module (see Figure 9). It is a motion tracker that combines several axes. It also allows the calculation of values from the gyroscope and accelerometer using a Digital Motion Processor (DMP) with a high processing rate, in order to provide results with low latency and sufficient accuracy.

Data extraction is done using registers or through a First In First Out (FIFO) stack. The difference between the two is that FIFO updates when an interrupt is called.

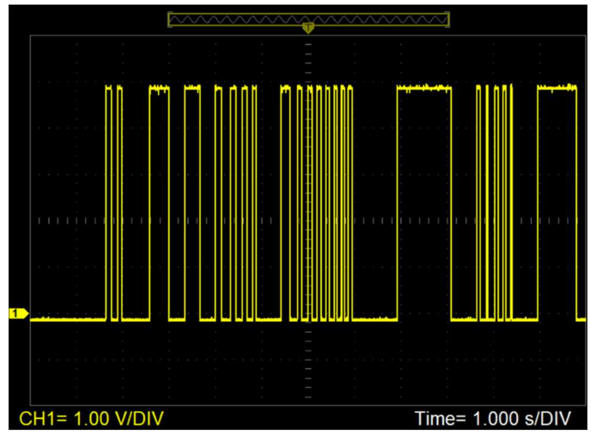

Fig. 8 Experimental dynamic command of the micro-motors

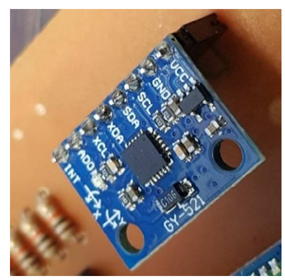

Fig. 9 MPU 6050 gyroscope and accelerometer-based module

4.2 Interconnection between virtual objects

For the concept of virtual environment with haptic feedback, it was also necessary for the interaction between two virtual objects to prove that a real-world user can "feel" the Virtual Reality through the haptic glove. For these reasons, it has been studied how the two virtually created bodies can interact with each other.

Making contact between two objects in the Virtual Reality environment involves using a *Collider*-type component and a *Rigidbody*-type component in order to be influenced by physical forces modeled by Unity.

This component is invisible and defines the shape of a *GameObject* object that aims to interact or even collide with another body behaving like a real collision. In this case, a *CompoundCollider* object was used, derived from the base *Collider* object, because it approximates the shape of the *GameObject* to keep a lower resource consumption. There also can be added *Collider* objects to get more flexibility.

When two *Collider* objects collide, they will be able to imitate the properties of the materials they represent, thus being able to simulate natural physical forces, such as friction.

Collider-type objects are configurable and allow the configuration of the material, friction and rigidity parameters through the *Physics Materials* property.

In this paper, the authors chose to apply these parameters on a simple cube object. These parameters have also been tested to see how objects interact with each other, if they come in contact or collide. For this purpose, several objects were selected whose necessary parameters were set to have the desired effect.

For the next step, *Trigger* methods were used to trigger certain actions when two objects interact. As can be seen in the case of Figure 10, the results of calling the methods in Figure 11 had the expected effect, which leads to the fact that in the case of using the glove with the 3D model of the hand will have the same effect and the micromotors will be successfully controlled, thus haptic feedback being obtained.

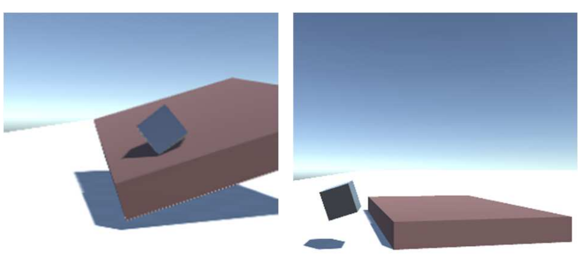

Fig. 10 Collision test between two objects

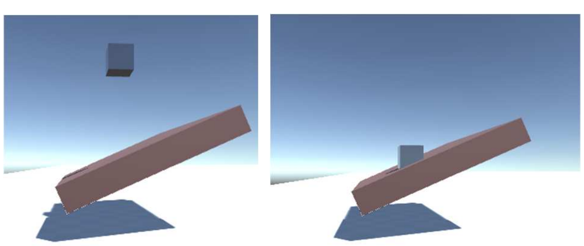

Fig. 11 Contact test between two objects to determine a reaction

For this test, it was considered that a reaction has to take place when the cube falls through the other object. As this action happens, a message will be printed in the Unity console.

After preparing all the components that make up the system and successfully testing in stages each of them, it was considered the right time to start integrating all the elements that make up the haptic glove.

5. INTEGRATION IN EDUCATIONAL APPLICATION

This paper focuses on the development of an experimental study for applications that can test the inputs of the control circuit of the haptic glove and getting the reaction from the virtual environment using:

- Micromotors,
- Flex sensors,
- Bluetooth technology,
- Gyroscope and accelerometer,
- Head Mounted Display,
- Unity 3D,
- Arduino IDE.

The haptic glove is used as a way of communicating with a simulated world. It is used to imply touch or restrict learner's gestures to mimic interaction with items or impacts within a scenario. The advantage of this will result in improved fidelity upon a scene by adding tactile sensation into the simulated world. Without the aid of feedback system, it can be challenging for a user to know whether he is touching a simulated item or surface. Figure 12 illustrates that in the case of a more complex task, the glove provides precise data for the 3D model to have a moving fluency, thus determining correct feedback when an interaction with an object in Virtual Reality takes place.

The user has a feedback directly proportional to the properties of the objects with which he interacts, but also to the force that he simulates at the impact with his hand in the virtual environment. Tactile feedback is critical in helping the physician retain healthy tissues, including identifying variations in stiffness across palpated areas; thus, allowing to identify any sign of tumorous section which will respond with a different stiffness and feedback. In order to be effective for medical education practices, a convincing sense of contact similar to the one encountered throughout an actual scenario must be replicated.

Fig. 12 Subject testing the interaction between haptic glove, HMD and the Virtual Reality environment

An improvement in human-machine interaction has also been observed while using Head Mounted Device in combination with the haptic glove. Using a Virtual Reality headset, in this experiment Oculus-Rift, the subject will scan the simulation while he uses software to execute a virtual operation that is somewhat close to the actual procedure.

For example, the first two years as a student in a medical school, one can practice mainly in the classroom setting, remaining less time for realistic medical scenarios. With Virtual Reality preparation, students will gain the ability to understand and integrate themselves in live medical situations even in the first years of college, facing it through a Head Mounted Device, from a first-person perspective.

The advantages of virtual reality medical training include, but are not limited to, interchangeable simulations, entirely manageable scenarios, automatic evaluation, limitless recurrence, that are now being proven in a number of different ways.

Having already a device that acts as a bridge between Virtual Reality and the user, which renders certain actions through the sense of touch, all that remains to be done is to develop a scenario that can be encountered in everyday life, especially in the educational environment. As a future work, the performance of such an approach will be analyzed and compared to the usual way of carrying out the teaching-learning activities.

For example, this haptic feedback system will be used to train medical students in preparing for future real-world scenarios using the resulted virtual training system. Several medical interventions use palpation as an additional interaction method and can therefore be identified as an effective basic process [8, 9].

Palpation is a procedure in which surgeons inspect abnormalities of tissues or organs, using their hands. Stiffness is the key to this kind of medicinal practice because certain areas that are stiffer than others can be referred to as possible tumors [10]-[13].

In this situation, the challenge of doing the palpation procedure on actual patients is reduced using the proposed simulated educational environment (see Figure 13) with the help of the feedback from the haptic glove.

Fig. 13 Palpation procedure in proposed VR simulated educational environment

The Virtual Reality learning scenario begins with the simple haptic task of getting the subject used to the haptic device for immersive evaluation of the student’s haptic management abilities. This aspect stops the student, from progressing to the next level until their cognitive abilities are improved on the basis of haptic feedback and immersion.

The next scenarios are based on the medical situations in which a liver can be healthy, enlarged or even have tumors according to different patients. In addition, various physical features including muscular flexibility, tissue tenderness, can be assigned to different simulated patients suitable for their age and gender, resulting in nearly infinite situations of schooling.

Results of this kind of immersive learning can prove that a student can be schooled to manifest a better adaptability to a real-world scenario using a haptic glove and to accustom him to the received feedback.

For the experiment in Figure 14, a hand movement that implies mostly moving the index, middle, and ring fingers in the medical procedure of liver palpation was considered. The waveforms presented in Figure 14, from the left to the right-side columns, represents:

- The control signal provided by the Arduino board for the control electronics;
- The output signal of the control electronics provided to the micromotors terminals;
- The actual internal speed of the micromotors measured in revolutions per minute (RPM).

All data was recorded during a virtual simulation of the actual medical procedure where two or more 3D objects collided in the virtual environment thus leading to haptic response of the glove. The numerical values used to generate Figure 14 were collected from Arduino, exported to a *.csv* file and afterwards imported to the Micro-Cap12 simulation tool.

The opportunity to naturally touch and communicate with simulated worlds is changing the way education and even businesses train their future specialists and put innovation into the market. The healthcare sector is the heart of this transition and is likely to be changed by developments in Virtual Reality and haptics. When it comes to medical preparation scenarios, haptic feedback is a key differentiator, but it has historically been achievable only with inert devices at a higher cost.

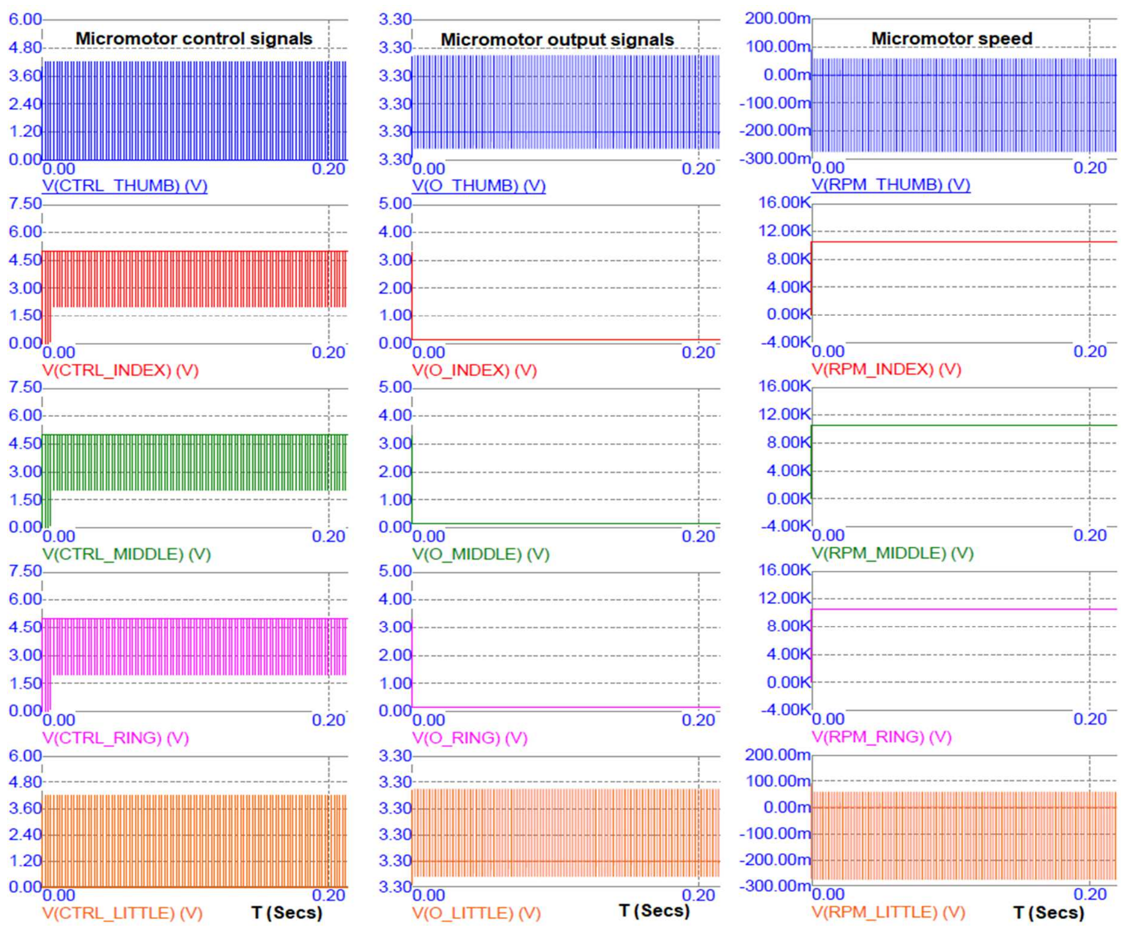

Fig. 14 Haptic feedback provided during a Virtual Reality simulated liver palpation – control, output and revolutions per minute waveforms for the micromotors

The experiments performed and presented through this section demonstrate that a glove developed in this way can successfully perform the task of providing haptic feedback through Virtual Reality in the case of medical palpation for educational proposes in a cost-efficient manner.

6. CONCLUSION

Walking down across this path, traditional ways of teaching and training will be upgraded to a new and enhanced form for the user to follow.

One of the most remarkable aspects of Virtual Reality and haptic feedback is that having a stimulus generated by Virtual Reality leads to faster growth of skills keeping in mind that haptic feedback involves muscles and nerves to react, allowing the user to be trained with the help of muscle memory.

Haptic technology can be useful not only in educational purposes, but also in training related applications for domains which refer to medical care, industry, and harsh environments.

For example, using a specific development environment for Virtual Reality, physicians can learn and comprehend essential techniques faster than using a traditional way of learning. This greatly reduces time and teaching materials, resulting in less expensive training.

This paper highlights the improvements that can be made not only for operators' reflexes and skills, but also for educational activities with a cost-efficient haptic glove system designed to mimic a quite natural state or operation. Availability of the patients is a major aspect and also, this kind of Virtual Reality system, resolves the problem from a legal point of view, considering that in different countries, students are constrained to practice only on laboratory assets that often are far from reality.

The authors aim to further improve and develop the presented system so that it will be applied for a wide segment of applications that also include other emerging needs.

7. AKNOWLEDGMENT

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8. REFERENCES

[1] Sziebig, G., Solvang, B., Kiss, C., Korondi, P., *Vibro-tactile feedback for VR systems*, 2009 2nd Conference on Human System Interactions, Catania, 2009, pp. 406-410, doi: 10.1109/HSI.2009.5091014.

[2] Burdea, G. C., *Rubber ball to cloud rehabilitation musing on the future of therapy*, 2009 Virtual Rehabilitation International Conference, Haifa, 2009, pp. 50-50, doi: 10.1109/ICVR.2009.5174204.

[3] Ganea, I. E., Resceanu, I.C., Bizdoaca, N. G., *Haptic devices synchronization into a software simulator*, 2017 18th International Carpathian Control Conference (ICCC), Sinaia, 2017, pp. 440-445, doi: 10.1109/CarpathianCC.2017.7970440.

[4] Manta, F. L., Dumitru S, Cojocaru, D., *Computer Vision Techniques for Collision Analysis. A Study Case*, 2018 22nd International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, 2018, pp. 427-432, doi: 10.1109/ICSTCC.2018.8540709.

[5] Cismaru, S.I, Besnea (Petcu), F.L., Trasculescu, A.C., Resceanu, I.C., Roibu, H., Bazavan, L.C., Ionescu., M., Bizdoaca, N.G., *Virtual simulation for a sensory glove with haptic feedback*, Proceeding of The 1st International Conference on Advanced Research in Engineering, CARE 2020, Craiova, 2020, pp.27-34, ISSN 2734-7400

[6] Popescu, N., Popescu, D., Ivanescu, M., Popescu, D., Vladu, C., Berceanu, C., Poborniuc, M., *Exoskeleton Design of an Intelligent Haptic Robotic Glove*, 2013 19th International Conference on Control Systems and Computer Science, Bucharest, 2013, pp. 196-202, doi: 10.1109/CSCS.2013.21.

[7] Tavares, R., Sousa, P. J., Abreu P., Restivo, M. T., *Virtual environment for instrumented glove*, 2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV),

Madrid, 2016, pp. 311-312, doi: 10.1109/REV.2016.7444488.

[8] Lupu, R. G., Ungureanu, F., Stan, A., *A virtual reality system for post stroke recovery*, 2016 20th International Conference on System Theory, Control and Computing (ICSTCC), Sinaia, 2016, pp. 300-305, doi: 10.1109/ICSTCC.2016.7790682.

[9] Escobar-Castillejos, D., Noguez, J., Neri, L., Magana, A., Benes, B., *A Review of Simulators with Haptic Devices for Medical Training*, Journal of Medical Systems, vol. 40, February 2016, https://doi.org/10.1007/s10916-016-0459-8.

[10] Ullrich, S., Kuhlen, T., *Haptic Palpation for Medical Simulation in Virtual Environments*, IEEE Transactions on Visualization and Computer Graphics, Vol.18, no. 4, April 2012, pp. 617-625. DOI 10.1109/TVCG.2012.46.

[11] Dinsmore, M., Langrana, N., Burdea, G. Ladeji, J., *Virtual Reality Training Simulator for Palpation of Subsurface Tumors*, Proceedings - Virtual Reality Annual International Symposium, 1997, pp. 54-60. DOI 10.1109/VRAIS.1997.583044.

[12] Sulema, Y., *Haptic interaction in educational applications*, Proceedings of 2015 International Conference on Interactive Mobile Communication Technologies and Learning (IMCL), November 2015, pp. 312-314, 10.1109/IMCTL.2015.7359609.

[13] Ramsamy, P., Haffegee, A., Jamieson, R., Alexandrov, V., *Using Haptics to Improve Immersion in Virtual Environments*, In: Alexandrov V.N., van Albada G.D., Sloot P.M.A., Dongarra J. (eds) Computational Science – ICCS 2006, ICCS 2006, Lecture Notes in Computer Science, vol 3992, Springer, Berlin, Heidelberg, pp. 603-609, https://doi.org/10.1007/11758525_81.

Integrarea unei mănuși haptice într-un mediu bazat pe realitatea virtuală pentru instruire și proceduri medicale

Rezumat: În timpul dezvoltării continue, tehnologiile de realitate virtuală (VR) propun noi provocări în ceea ce privește imersiunea parțială sau totală într-un mediu simulat folosind un computer și un dispozitiv montat pe cap (HMD). Astfel, au fost create instrumente pentru a oferi noi mijloace de interacțiune cu mediul înconjurător, dar cu avantajul de a preveni acțiunile dăunătoare, făcându-le astfel instrumente perfecte și extrem de versatile pentru instruire. Cunoștințele dobândite în timpul experimentelor și simulărilor efectuate de autori în cercetările anterioare, bazate pe dezvoltarea unei mănuși senzoriale, demonstrează că acestea poat fi aplicate în probleme medicale, intervenții chirurgicale și chiar în recuperarea pacienților. Scopul acestei lucrări este de a integra o mănușă senzorială cu feedback haptic într-un mediu virtual, pe care o persoană îl poate folosi pentru a experimenta un nou mod de învățare într-o situație reală și posibilă, fără a-și asuma riscuri. Noutatea constă în dezvoltarea de dispozitive care facilitează instruirea prin aplicații VR într-un mod rentabil.

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