PROTOTYPE SYSTEM FOR UPPER LIMB REHABILITATION USING VIRTUAL REALITY

PROTOTIPO DE SISTEMA PARA LA REHABILITACIÓN DE MIEMBROS SUPERIORES MEDIANTE REALIDAD VIRTUAL

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Abstract

This article shows the implementation of a virtual tool that can be used as a support in upper limb rehabilitation processes. The tool was developed with the Unity 3D graphics engine, along with the use of a smartphone and a support device, in order to project the virtual world onto the user's eyes. A QR code attached to the back of the user's hand allows the smartphone camera to locate the user's hand at all times. The tool was tested with 30 students and health professionals, obtaining good acceptance and foreseeing its great potential as a support in the rehabilitation processes they carry out.
Keywords: Upper limb rehabilitation, virtual reality, unity 3D, smartphone y VR box.

Resumen

Este artículo muestra la implementación de una herramienta virtual que puede ser utilizada como apoyo en procesos de rehabilitación de miembros superiores. La herramienta fue desarrollada con el motor gráfico Unity 3D, junto con el uso de un teléfono inteligente y un dispositivo de soporte, con el fin de proyectar el mundo virtual en los ojos del usuario. Un código QR adjunto al dorso de la mano del usuario *permite que la cámara del teléfono inteligente ubique la mano del usuario en todo momento. La herramienta fue probada con 30 estudiantes y profesionales de la salud, obteniendo buena aceptación y vislumbrando su gran potencial como apoyo en los procesos de rehabilitación que realizan.*

Palabras clave: *Rehabilitación de miembros superiores, realidad virtual, unity 3D, smartphone y VR box.*

1. Introduction

Virtual reality has spread very rapidly in recent years, moving out of its original environment of video games for which it was developed. This new technology allows the creation of an environment where information and virtual objects merge with real objects, offering a significant cohesion to the user's daily reality [Rubin, 2018].

One of the new fields of application of this technology is healthcare, specifically upper and lower limb rehabilitation. Intensive therapies based on virtual, augmented or mixed reality, promote the motor recovery of limbs for patients who have suffered strokes, allowing an improvement in mobility, balance and endurance [Chen, 2022]. Combining conventional rehabilitation with virtual reality technology, serious webcam-based games have been developed for the rehabilitation of affected limbs [Burke, 2010], [Ayed, 2019]. Other studies describe that virtual reality in gamified environments helps to motivate patients to perform rehabilitation exercises in a more enjoyable way, partly reducing pain in the sessions [Muri, 2013], [Jonsdottir, 2018]. The use of exoskeletons together with virtual reality can also improve patient mobility [Hoffman, 2020], [Domínguez, 2019].

There is a worldwide increase in the number of people going through accidents or illnesses that partially or totally limit mobility in some part of the body. Specialized virtual or augmented reality devices involve significant capital outlay for healthcare providers [Lo, 2019]. This is why research on efficient and low-cost rehabilitation systems is beginning to be seen [Standen, 2017]. One of them involves the use of an inexpensive device that can hold a smartphone, from which rehabilitation therapies are programmed and executed. This article shows the implementation of such a device and its validation with students and health professionals.

2. Methods

Application description

For the development and operation of the application it is necessary to have a mid-range smartphone and a VR Box (virtual reality glasses for smartphone - figure 1), in order to achieve user immersion within the virtual world. In this particular case the smartphone used was a Huawei model Y9 2019, with Kirin 710 processor, 13 / 2 mp dual camera and 3 Gb RAM. In order for the system to read the position of the user's hand in the real world, it uses a QR code that detects the limb and sends this information to the virtual world.

Figure 1 Smartphone and VR Box used.

The application is based on the movement of the upper limb through the basic anatomical planes, which allow movements in horizontal, vertical and diagonal directions. In this way, the user interacts inside a striking virtual space where objects will appear in random distance ranges, separated according to the difficulty defined for each game mode. The therapies defined for each mode are:

- Axial: Designed for therapies involving horizontal movement. The range of movement is limited to 1 meter in easy mode, and 2 meters in normal mode, defined on the x-axis.
- Sagittal: Designed for therapies involving vertical movement. The range of motion varies between 1 meter and 1 ½ meters, depending on whether in easy or normal mode respectively, with defined movements on the y-axis.
- Mixed: Designed for advanced therapies where targets can appear anywhere in the virtual room.

In each of the game modes the user must manage to collide the QR code on the back of his hand with the objects that appear randomly in the virtual world, performing, with the supervision of a health professional, the correct movements to treat his injury. At the end of each session, a tally of each session is kept, as well as a score to keep track of the patient's progress in their treatment.

Engine of development

Unity 3D is used for the development of the application, a multiplatform graphic engine widely used in video games and other applications that require a high degree of realism [Hernández 2018]. For the software developed, Unity 3D allows exporting the application to different devices, changing the command control and going from a 2D interface where the therapy is started to 3D, where the user executes the exercises

Application identity

The developed application was called Slime Catches. Because rehabilitation devices are not always easy and intuitive to use and interest (and in turn rehabilitation) depends on the interface and playability of the application [Shi, 2018], a visually friendly environment was generated that can help the patient feel more comfortable with performing their therapies.

Main screens

The home screen allows access to the other sessions by recognizing the user by means of his or her identification number. The registration screen (Figure 2), allows the user's most important data to be entered and registered. This data can be seen in an additional screen, as well as the number of sessions performed, and data on the last and best score obtained (Figure 3). On the other hand, the sessions screen allows visualizing the number of sessions performed in each of the anatomical planes and their respective levels. The session options screen (Figure 4) presents the user with the different anatomical planes available for the session to be worked on (sagittal, transverse and mixed). Finally, the recommendations screen displays five important recommendations for the correct functioning of the application, as well as two level variations (normal and difficult) for the sagittal and transverse planes.

Figure 2 Registration screen.

Figure 3 User data screen.

Figure 4 Session options screen.

Applied development environment

The application works primarily by tracking and interacting with a QR code attached to the back of the user's hand (Figure 5), which is captured by the smartphone camera attached to the VR Box. This camera identifies depth and movement, which are reflected in a virtual 3D illustration, similar to a human limb linked to the QR code (Figure 6). In this way, spatial feedback is achieved in the virtual environment, where targets appear and disappear within a specific area depending on the game mode (Figure 7).

Figure 5 Back of the hand with QR code.

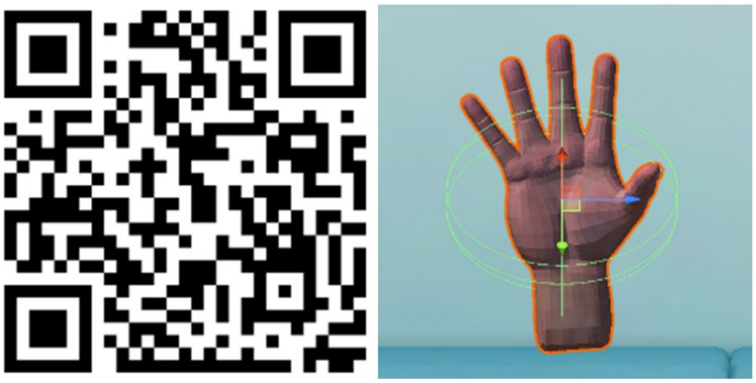

Figure 6 QR code and 3D illustration.

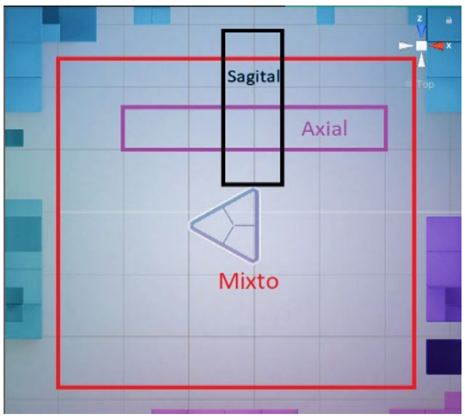

Figure 7 Areas according to game mode.

As explained above, the application has 3 game modes: transverse or axial mode, where horizontal movements of the upper limb are evaluated; sagittal mode, where vertical movements are evaluated; and mixed mode, where combined movements are evaluated. For the transverse and sagittal modes there are two levels, the easy level where the slimes appear closer to the user, and the normal mode where the distance ranges are higher. In each level, although there is no maximum limit of slimes, the exercise session is limited to 5 minutes in order not to cause user fatigue. The functionality of the Slime Catches application allows to compare the movements between the real space where the user moves, and the virtual environment where he should come in contact with the slimes, which will motivate the movement of his upper limb. This is represented in the operation diagram in figure 8.

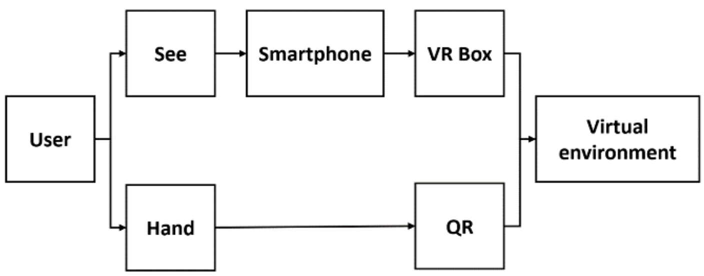

Figure 8 Operating diagram.

A view of what the user sees in front of his eyes once the smartphone and the VR Box device are in place is shown in figure 9. The person will be able to see his or her hand (identified by the QR code present on the real hand) inside the virtual environment, and the slime to be touched.

Figure 9 User's view with the device placed in front of the user's eyes.

3. Results

Third party testing

The Slime Catches application is implemented as a support tool, which can be used by health professionals, specifically physiotherapists, as an aid for rehabilitation sessions of their patients with upper limb conditions such as shoulder and arm. For this reason, once the first version of the application was completed, it was tested with students and professionals from the Faculty of Health of the University of Cauca, Colombia (Figure 10). The test was carried out with a sample of 30 individuals, distributed between the Medicine and Physiotherapy programs, both students and professionals, with sessions of a maximum of 5 minutes to test the application.

Figure 10 Testing with students and professionals.

Surveys

Once the test had been carried out with the users, a survey was conducted with them, in order to obtain feedback on the operation and potential of the application. Sixteen questions were asked, which are shown below, table 1.

Analysis of survey results

The results of the surveys reflect a good performance of the application in general. The most relevant results are detailed below.

Figure 11 shows the score obtained on the tracking between the 3D environment and the QR code, which is the basis of the system operation. The result shows that in general a good spatial feedback is obtained between the real movement and its virtual representation.

Table 1 Survey questions.

N°	Questions
1	What age range are you in?
2	How would you rate the overall performance of the application?
3	If your answer above was fair or poor, please explain your answer.
4	How would you rate the QR code tracking through the camera?
5	If your previous answer was fair or poor, please explain your answer.
6	Did you find the application appealing or eye-catching?
7	If your previous answer was "No", why?
8	Do you feel that the app meets your primary rehabilitation objective?
9	If your previous answer was "No", why?
10	During the time of using the app, did you experience any of the following symptoms?
11	Would you use the app with your patients?
12	If your previous answer was "No" why?
13	If your previous answer was "Yes" On what occasions or treatments would you use the app?
14	Do you consider that the app helps shoulder mobility in all its possible movements?
15	What improvements from your professional point of view would you implement in the app?
16	What problems do you see in the app?

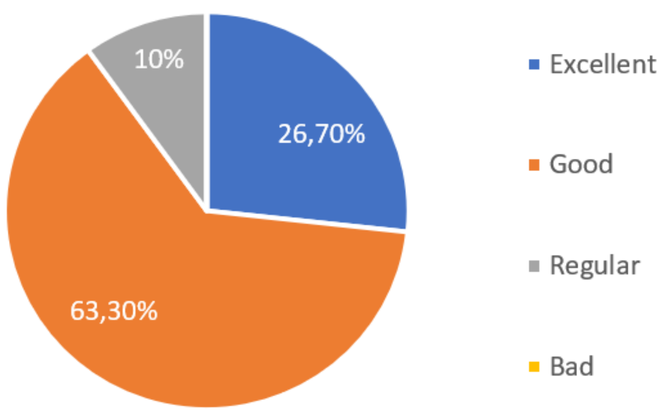

Figure 11 QR code tracking qualification.

Figure 12 represents the results obtained in response to the question "Do you consider that the application helps shoulder mobility in all its possible movements? In other words, the aim is to find out whether, in the opinion of the experts in the area, the application develops the necessary elements for upper limb rehabilitation, obtaining an affirmative answer in most cases.

Figure 13 presents the overall results of acceptance of the application by the health personnel who took the test. It can be seen that the application was fully accepted by the respondents. The word cloud in figure 14 groups the possible conditions that could be treated by the application according to the respondents.

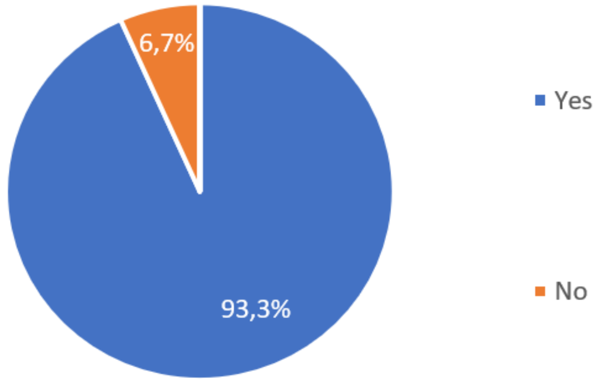

Figure 12 Rating about shoulder mobility.

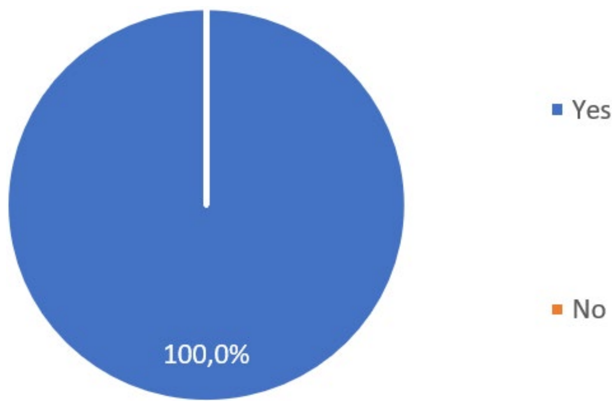

Figure 13 Application acceptance rating.

Figure 14 Word cloud of possible conditions where the application might help.

Finally, the bar graph in figure 15 exposes the various discomforts that users experienced when using the application, mainly due to the sensory confusion that the use of the smartphone mounted on the VR Box can mean. Although these discomforts may be present, their presence in the experiments was in any case low. It is also expected that over time this type of situation will decrease as the technology and the quality of the image received by the users improve.

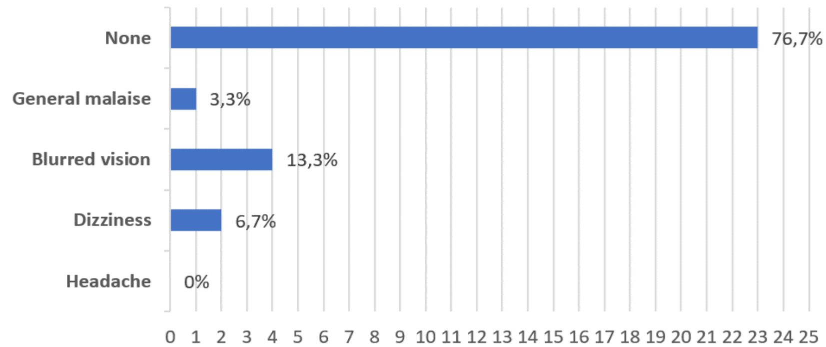

Figure 15 Discomfort generated by the use of the application.

4. Discussion

According to the results obtained, it is possible to observe similarities with the ideas put forward by [Chen, 2022] where the fields of application, specifically the rehabilitation of upper limbs based on virtual reality, favors recovery by allowing the mobility of the shoulder in all its possible movements. In addition, the validation of health professionals regarding the operation of the tool, allowed determining the possible implementation of the same for different patient pathologies, corroborating that, combining conventional rehabilitation with virtual reality technology, it is possible to generate an increase in the motivation of patients to perform rehabilitation exercises and complete the sessions in a more enjoyable way, similar to that described in the ideas presented by [Muri, 2013] and [Jonsdottir, 2018] where a relationship between virtual reality technologies for rehabilitation and patient motivation to perform these same is managed to develop.

5. Conclusions

The present work showed the implementation of a virtual reality system that can be used as an aid in upper limb rehabilitation therapies. The designed system makes use of a support (VR Box) for a smartphone, where the virtual reality system was designed. The system, called Slime Catches, was built with the Unity 3D graphics engine.

The application allows the user's data to be entered and saved, in order to follow the user's evolution over time. A QR code attached to the back of the user's hand allows the smartphone camera to detect the position of the hand at all times, which can then be represented in the virtual world. In this world, various objects appear and disappear that the user must catch, with the system recording the successful cases as well as the time taken to complete each task.

A sample of students and professionals from the Medicine and Physiotherapy programs validated the tool. Surveys conducted after the tests show the great acceptance of the tool and its potential as a support for upper limb rehabilitation processes. It is worth highlighting the importance of the motivation that tools of this type can bring to the process of patient improvement.

Future work will improve the developed system using more advanced devices, e.g. the Oculus Rift headset, as well as the first tests with real patients, in order to prove its true potential.

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