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Visual feedback framework for rehabilitation of stroke patients

Piedad A. Semblantes, Víctor H. Andaluz, Johana Lagla, Fernando A. Chicaiza*, Andrés Acurio

Universidad de las Fuerzas Armadas ESPE, Sangolquí, Ecuador

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ABSTRACT

The article describes an alternative for the rehabilitation of upper and lower limbs using visual feedback to treat the sequelae of stroke. The Framework contains three-dimensional scenarios which require patient immersion in an intuitive exercise routine supervised by the attending therapist, who further corroborates visually the progress of the recovery. This work is also supported by a DTW algorithm. The algorithm is based on the collection of data through tracking sensors and the identification of the exercise patterns performed by the patient. The delivering of a satisfactory response in case the exercise is completed correctly will support the evaluation of the therapist in the advance of the therapy. The experimental results show the execution of the exercises proposed with different users in order to validate the usability of the framework.

1. Introduction

The number of patients attending health centres with stroke has been increasing. Globally, this pathology presents the second cause of more common illness, while in Ecuador it is one of the main causes of disability according to the National Statistics and Census Institute of Ecuador (INEC) [1]. This failure occurs in the right and left lobes, causing partial or total loss of body movements, difficulty in understanding or articulating words, and can range from cognitive damage to a vegetative state. The common methods of treating the sequelae left by stroke are presented as unfruitful and tedious therapies for the patient. These processes tend to be routine and exhausting, and patients often drop out of treatment due to external factors such as the availability of time, the high cost of rehabilitation, or the lack of motivation to continue with this process [2].

Many of the treatments for severe, moderate, and mild stroke highlight the need to find options using new technologies, with virtual reality being one of the technologies with the best performance [3]. At present, this technology has made significant inroads in the treatment of this type of disease, where the inclusion of sensors greatly improves the user-virtual environment interaction. With this background, Neurofeedback techniques can be used in the treatment of severe motor impairment by integrating a low-cost portable electroencephalography (EEG) and electromyography (EMG) system [4]. This technique, along with visual feedback, is used to receive brain and muscle data, integrate and analyse them in real time, provide virtual reality feedback for the patient, and furnish information for the treatment therapist [5]. In the same way, in Ref. [6], a system is developed for the rehabilitation of patients with mild to moderate stroke and paraesthesia symptoms. This platform consists of an intuitive virtual reality interface, which together with a haptic device, collects information from the exercises performed by the patient and transmits them to the visual feedback environment. The inclusion of this type of treatment in the area of medicine aims to provide a clear vision for patient recovery to the physical and occupational therapists, recording the evolution of the treatment and optimizing the time of rehabilitation. Additionally [7], proposes a Kinect-based system for cognitive rehabilitation exercises monitoring, where the tracking of left and right hand, face, and facial detection allows the system to extract the achievement level, to calculate temporal parameters, and to track the trajectories of human body parts in the psychomotor exercises. Although there are plenty of applications based on VR with rehabilitation aims, a system to evaluate exercises with upper and lower limbs has not been specifically proposed, where the tracking of the user's whole body with a camera array can remedy this gap.

On the other hand, the support provided for the specialist in traditional rehabilitation is extremely important to the patient to reach expected results, where a series of routines to increase the mobility of the affected extremities are suggested for the specialist. When using technology to validate the exercise regimen, different types of alignment algorithms and classifiers can be used [8]. These type of algorithms validate experimentally the approach between two groups of values distributed over a defined period of time, where strategies based on neural networks, identification techniques, algorithms by demonstration, and other techniques can be used [9,10]. In relation to this,

* Corresponding author.
E-mail addresses: pasemblantes@espe.edu.ec (P.A. Semblantes), vhandaluz1@espe.edu.ec (V.H. Andaluz), jelagla1@espe.edu.ec (J. Lagla), fachicaiza@ingenius-scitech.com (F.A. Chicaiza), andyacurys@hotmail.com (A. Acurio).

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diverse works have been developed in different areas, such as simulation of the grip of a robot in virtual reality using a demonstration algorithm [11–13] employ techniques which consist of the development of intuitive strategies that provide the robot with the possibility of learning instructions from one or several demonstrations executed by the human operator to perform manipulation tasks in a VR environment. In Ref. [14] is implemented a virtual reality system focused on the learning of ballet dance routines, in which a Dynamic Time Warping (DTW) algorithm is utilized to measure the degree of coincidence of the student's dance sequences with those of the teacher. The data needed for the algorithm are taken from a tracking device (Kinect), considering that the student is totally immersed in this VR environment [15,16]. However, by emphasizing the area of applied robotics, a representative number of works that focus on the inclusion of virtual reality is developed through the use of alignment algorithms. In this context, alignment algorithms can be used in parallel with VR technologies to evaluate the execution of movements of a user, who may be using the virtual medium for entertainment, education, or rehabilitation.

Thus, given that virtual reality is immersed in a range of solutions for different technical areas [17] and health [18,19], this work proposes the design and implementation of a virtual rehabilitation system, where the patient has the opportunity to interact intuitively in an environment of daily life, and perform a series of rehabilitation routines. The movements that are intended in the rehabilitation routine are used to treat minor injuries left by a stroke, focused on exercises for each of the affected limbs. This article proposes a set of games which, in gradual sessions supervised by the occupational therapists, assist in the recovery of the mechanical function of the upper motor neuron affected by a stroke. The system mentioned in turn implements a classification algorithm, referring to the techniques of identification of patterns given by the DTA (dynamic temporal alignment) algorithm. This algorithm aims to measure the homogeneity of the information of the sequences obtained from a tracking device (Kinect) with respect to a pre-recorded model of the exercise used for treatment [20]. In addition, the system includes a database manager which allows maintenance in detail the history of the person with stroke who has been and is being treated using this framework. The main aim of this work is to propose a technological alternative to the treatment of physical sequelae left by stroke, motivating the patient to continue with the rehabilitation sessions through entertainment activities based on virtual reality, self-educating the user for the correct execution of exercises, and to encourage them not to abandon therapy.

2. Task evaluation

The development of the application is based on the technology Kinect v2 which enables objective and accurate measurement of the positions of the main joints of the human body. For the evaluation of the movements during the execution of the test, the final positions of the reference points in the extremities, the vectors used are; $\mathbf{a}_{pq}$ for the arm, where p: represents the exact point of reference of s = shoulder, e = elbow, w = wrist, h = hand, t = thumb y ht = tip of the hand; and the position of the arm r = right or l = left, that is the vector $\mathbf{a}_{sr} = (x_{sr}, y_{sr}, z_{sr})$ would represent the position of the right shoulder; of similar shape for the leg $\mathbf{l}_{pq}$, where p: represents the exact point of reference of h = hip, k = knee, a = ankle, and f = foot; and $q{:}r$ = right or l = left; for the central part of the body the references are considered: $\mathbf{t}_h$ for the head, $\mathbf{t}_{sh}$ for the central part of the shoulders, $\mathbf{t}_s$ for the central part of the spine y $\mathbf{t}_h$ for the central part of the hip. The diagram shows the skeleton of the user represented by 24 points, the position x–y–z of the reference points is obtained through the function Skeleton Frame Ready with respect to a global reference $<R^3>$ frame located on the Kinect device.

The application used is executed within the vector space of $<R^3>$. To measure the angles of the limbs in different positions we use metrics defined in an Euclidean Space, for the angle measurement the

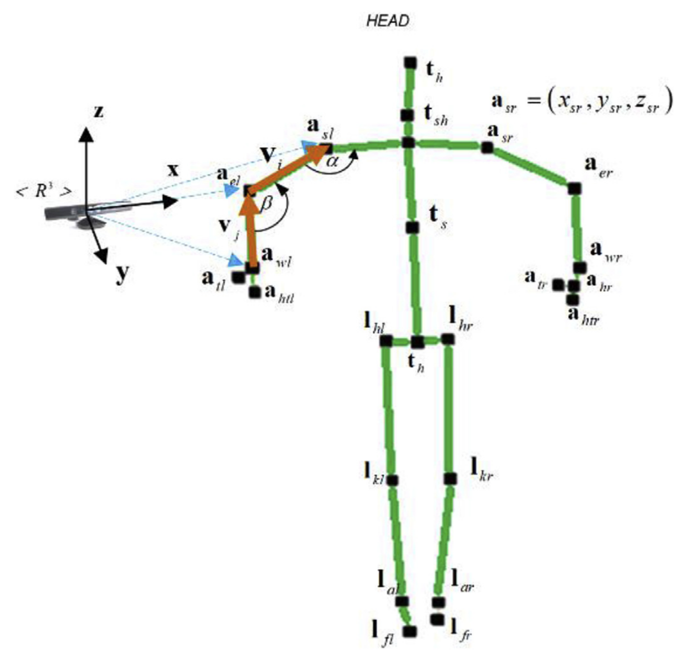

Fig. 1. Representation of the assessment of the test and Tracking points through Kinect v2.

expression is used $\cos\theta = \frac{\langle \mathbf{v}_i \cdot \mathbf{v}_j \rangle}{\|\mathbf{v}_i\|\|\mathbf{v}_j\|}$, where $\mathbf{v}_i$ and $\mathbf{v}_j$ are obtained from the difference between the coordinates of the reference points, *e.g.*, $\mathbf{v}_i = \mathbf{a}_{sl} - \mathbf{a}_{el}$ and $\mathbf{v}_j = \mathbf{a}_{el} - \mathbf{a}_{wl}$, to obtain the modulus of the vectors representing the limbs we use the definition of norm $\|\mathbf{v}_i\| = \sqrt{\langle \mathbf{v}_i \cdot \mathbf{v}_i \rangle}$; with these data one can evaluate each of the tests that are required, see Fig. 1.

3. Virtual rehabilitation system

The implemented system is based on an interaction architecture between the patient and the virtual reality environment via a physical device (Kinect v2). Through a set of scenarios, this system proposes an alternative to rehabilitating lesions left by the stroke at a mild-moderate level. Fig. 2 shows the structure of the system developed. The proposal is characterized by providing levels of difficulty (high, moderate, and slight) to rehabilitation, stimulating the mechanical function of the upper motor neuron injured by the stroke.

The proposal considers an algorithm based on the comparison of the exercises pre-set by the occupational therapist (called the model sequence) and the exercises performed by the patient (called the analysed sequence). During rehabilitation, this information is acquired by the tracking device to be processed and evaluated by a real-time

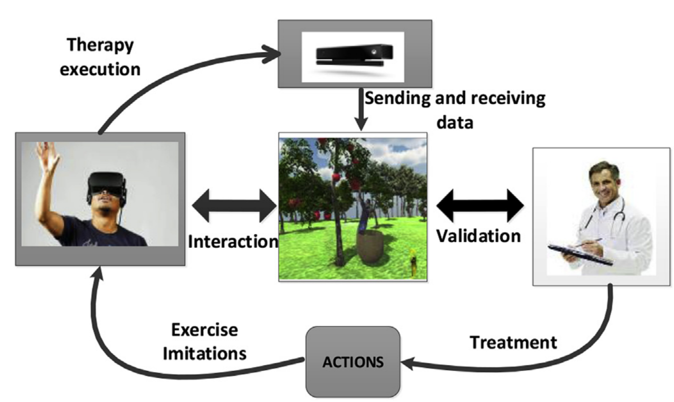

Fig. 2. Structure of the stroke rehabilitation system.

mathematical software. The algorithm provides feedback to the virtual scenario to determine the validity of the task performed by the patient during the therapy.

In the virtual environment, the patient is represented by an avatar in the game environment, in order to perform the activities proposed by the therapist depending on their level of paraesthesia. With the fulfilment of the rehabilitation program, the system provides information such as the time elapsed in the correct development of the exercise, the date, the patient's personal data, and details of the pathology with which he/she started the rehabilitation. This information enables the evaluation of treatment progress by the attending therapist.

4. Operating scheme

The interaction between the patient and the virtual environment is done through the tracking of the user's skeleton by means of the HD and infrared cameras sensor, in order to contribute with the input to the virtual environment. The development of the virtual environment should allow interaction between the patient and the avatar. The movements of the avatar are executed according to the actions the patient performs in the accomplishment of the exercise routines. The proposed block diagram splits the system into five parts: system inputs, control design, communication, virtual environment, and outputs, as shown in Fig. 3.

The *a) inputs* of the system are devices for signals acquisition, for later interpretation of them, and executing an action to modify the virtual environment. The virtual devices used as inputs are: i) a virtual reality helmet, which provides immersion to the VR environment with the purpose of encouraging the patient to perform the exercises proposed by the therapist and (ii) a Kinect 2.0 sensor, which provides the position and rotation information of the skeletal bones of the patient. The characteristics of low latency, high accuracy in information acquisition, and joint location show that the Kinect sensor is suitable for this research.

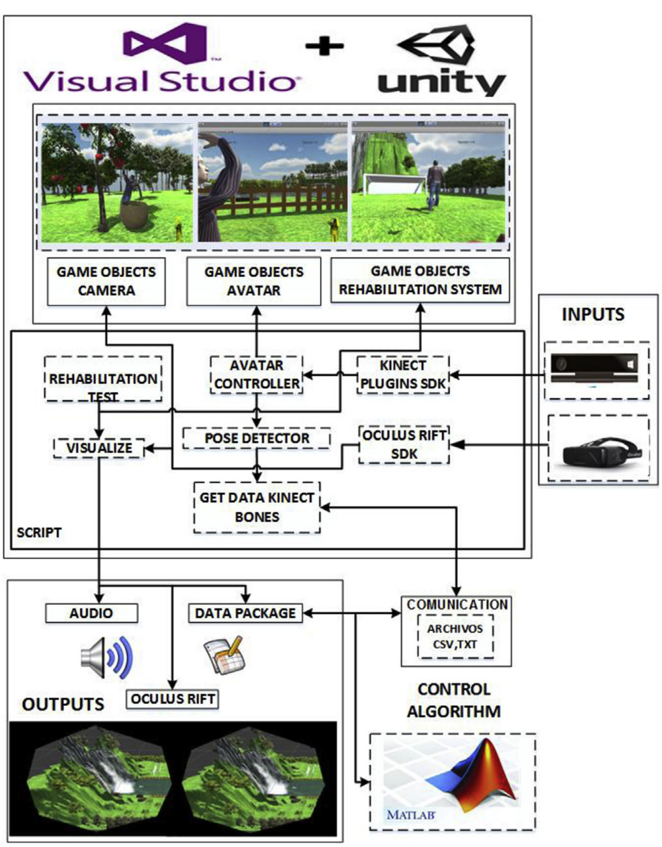

Fig. 3. Operating scheme diagram.

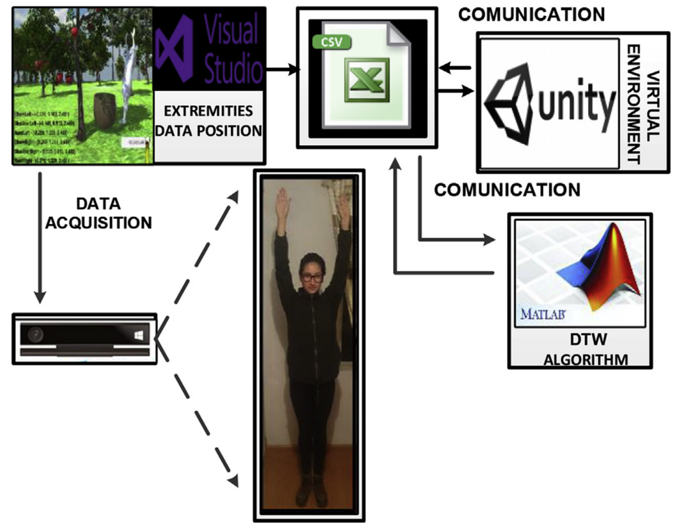

Fig. 4. Framework design.

In the *b) algorithm design block*, the evaluation of the distance between two sequences is developed, between the routine performed by the user and the model predefined by the specialist. The predefined model is determined from the sampling of 15 sequences and their average. The new information provided by the user (given by a new executed sequence) does not always have the same size as the pattern vector, where the main cause is the speed of execution or the elapsed time in which the patient performs the indicated task. In order to solve this problem, a temporal alignment between both signals is proposed, to later calculate the Euclidean distances between them and to determine the degree of coincidence between them, as shown in Fig. 4.

The *c) communication layer* determines how the virtual environment and mathematical analysis software communicate with each other. For this type of application, a *.csv file handling is appropriate for the exchange of information between both programs. Through *.csv files, vectors of x, y and z position of analysis points are stored and shared bidirectionally. Each program accesses this file to read and record the necessary information for the interaction within the virtual environment, and the analysis of the algorithm, respectively.

In *d) virtual environment*, an intuitive interface is programmed to capture the attention of the patients, motivating them to complete an exercise routine. The virtual environment was implemented through the integration of pre-designed virtual objects in the Unity 3D platform, where the respective programming scripts are used to interact with the inputs and outputs of the system (Fig. 4).

The *e) outputs* of the system emit sounds through the helmet, to provide information on the development of the exercise. Visual feedback is provided by the virtual reality helmet and, additionally, the system also produces a report with relevant data concerning the execution of tasks, in order to be evaluated by the specialist.

5. Multilayer development scheme

This section describes the multilayer scheme for the development of virtual reality systems as a method for the treatment of strokes. The proposed system allows one to modify the configuration of any of the scenes, adapting them to the needs of the affected. The proposed scheme has 4 layers with the following distribution: (i) Layer 1: in charge of the design of the virtual reality environment; (ii) Layer 2: intended for the execution of the task and configuration of the inputs which interact in the system; (iii) Layer 3: develops the algorithm that manages the validation of rehabilitation routines; and (iv) Layer 4: records the acquired data for therapy evaluation - see Fig. 5.

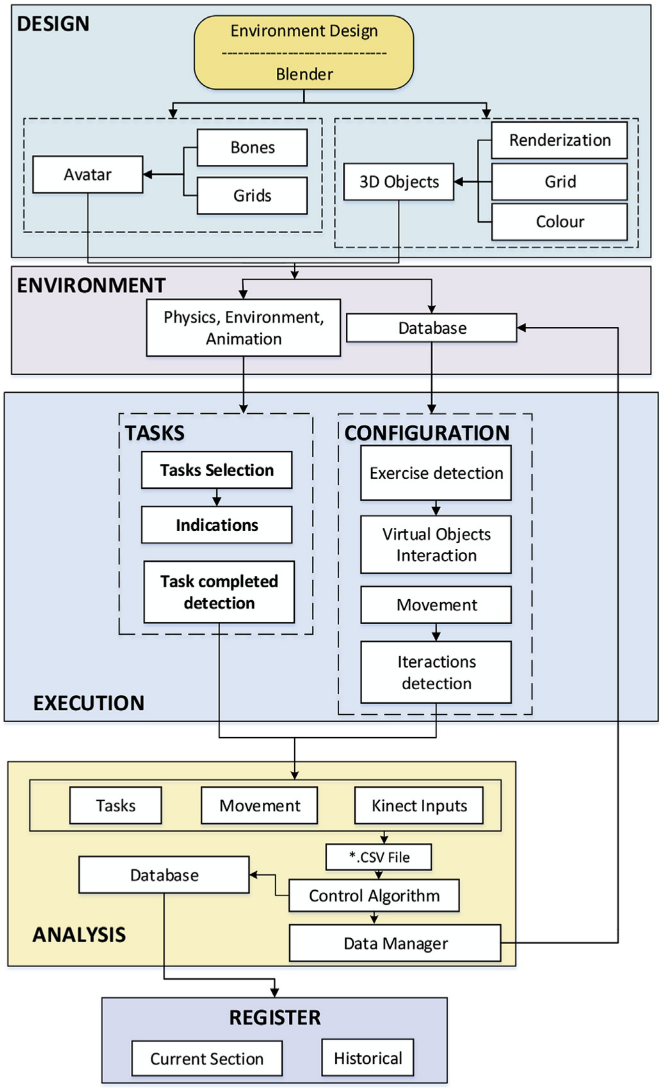

Fig. 5. Development of the multilayer scheme.

5.1. Environment design

This layer enables the development of the interaction environment between patient and virtual reality, where each of the 3D objects which will be linked to the therapy is located, e.g. butterflies, birds, fish, waterfall, among others. These objects are built in Blender design software, since this is one of the software types which provide *.fbx files and is freely distributed. The avatar designed for this system is created by the software Make-Human, which is exported with textures and skeleton characteristics in *.fbx extension, facilitating the manipulation of the same by means of the tracking device. For objects designed in Blender, textures, meshes, rendering, and colour are created to give more realism to the virtual environment. The resulting files are compatible with the Unity 3D graphics engine.

5.2. Configuration and tasks

In layer 2, two sublayers are considered as follows: *(i) Input configuration*: the interaction of the user with the elements that compose the virtual environment is given by the tracking provided by the Kinect. The tracking determines the movements performed by the avatar on the interface, while the Oculus Rift device is used for immersion in the environment. The configuration of the input devices is performed by the functions of OnTriggerEnter(), Instanciate() and Destroy(), used for interaction with virtual objects. At the same time, the framework keeps track of each of the exercises performed. And *(ii) Task:* this section selects the type of task according to the patient treatment level. If it is their first rehabilitation session, the program configures a level 1 with a slight complexity and the execution of 5 repetitions in each scenario. Indications are provided through animation objects to lead the patient in the exercise they should perform. The detection of completed tasks is implemented to know the exact moment in which the user completed the test using Scripts, counting the correct interactions that were made in the virtual reality environment.

5.3. Analysis and alignment

In layer 3, two important aspects, such as analysis and detection of the pairing of movements in the RV environment, are treated. The analysis of the data provided by the Kinect input device depends on the task being executed, generating information on the movements of the patient. The storage of these data is in the form of vectors with positions in X, Y, Z. These vectors are formed according to the points evaluated in the exercise, considering for the upper extremities 6 points (wrist, elbow, shoulder) and for the lower extremities 4 points (knee, foot). These data are saved in *.csv files, to be sent to the mathematical analysis software. The pairing detection is performed by the DTW algorithm, which is specified in section V. Finally, a database is generated based on the exercises performed and the results obtained in them. These data give feedback to the virtual reality environment, generating a satisfactory output if the distance is considered in the proper range. Given a successful result, the interface provides both an audio and a visual response.

5.4. Registration

In this section, historical data on the evolution of the patient is generated according to the constancy that he/she present in the treatment, which will be useful when a diagnosis is made by the therapist.

6. Algorithm

Each of the movements performed by patients with stroke must be specifically recognized for the recovery of the patient in an efficient manner. This requires a mechanism to verify that the patient is developing the exercises correctly. Therefore, this work proposes the implementation of the DTW algorithm based upon the comparison and analysis of two vectors or sequences of values in order to find an optimal alignment.

The vectors obtained from both the pattern and the exercise sequences are defined as:

$$A = [(x1, y1, z1),\ (x2, y2, z2),\ .....(x_n, y_n, z_n)]\ \forall\ n \in\ R^3,$$

$$B = ([(x1, y1, z1),\ (x2, y2, z2),\ .....(x_m, y_m, z_m)]\ \forall\ m \in\ R^3,$$

where the A sequence represents the defined model of the rehabilitation system, while the B sequence is the exercise performed by the patient, which will be compared to the model in order to obtain the error threshold.

After knowing the vectors A and B, a vector space F formed by the points of the upper and lower extremities according to the exercise performed is defined, so that:

$$x_n,\ y_m\ \in F,\ \forall\ n \in [1, n],\ \forall\ m\ \in [1, m] \quad (1)$$

The vector space, when comparing the two sequences obtained by the vectors, requires the input of an internal distance, which is defined by (2):

$$c(A, B)\colon F \times F \to R \geq 0 \quad (2)$$

The function calculates the distance between each pair of elements

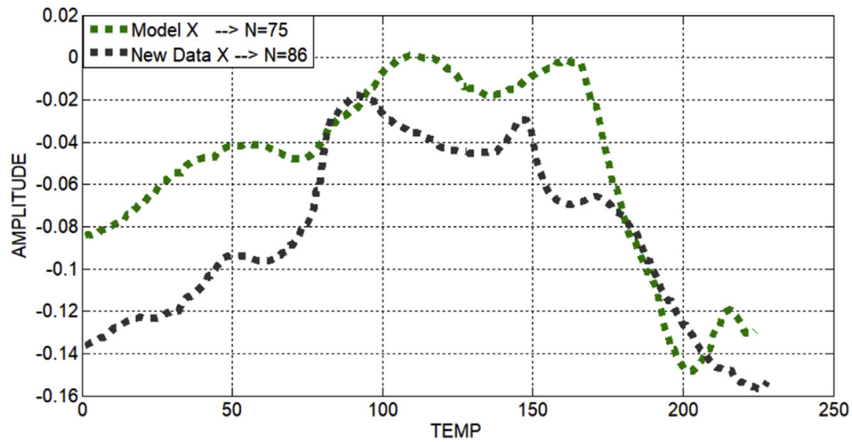

Fig. 6. Model sequence and new data sequence.

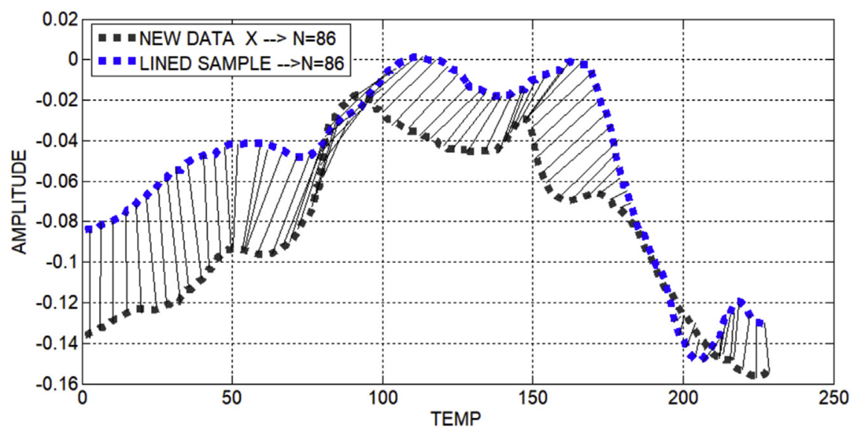

Fig. 7. DTW algorithm in both sequences.

Fig. 8. Stretching of upper limbs.

Fig. 9. Supination of arms.

of the A and B sequences, obtaining a matrix of costs $c \in R^{n \times m}$ which represents the magnitude of difference between pre-configured movement patterns versus the vector of movements generated by the patient. The function will return a small cost response $c(A, B)$ if A and B are similar, and a raised cost response $c(A, B)$ if they are very different.

The matrix allows an adjustment of the vectors A and B to achieve an optimal alignment throughout the development of the exercises, which define a sequence:

$$p = (p, p2, \ldots, pL), \ \ with \ pl = (nL, mL) \in [1, n]x[1, m], \ \ \forall \ L \ \in [1, L] \tag{3}$$

From the matrix of the DTW algorithm it is shown that both sequences interact in a similar way, being this matrix is that to which the Euclidean distances are applied to. The Euclidean distances are the result of comparing the pattern sequences (pre stored patterns) together with the acquired movements.

Both the model vector and the vector of the user's movements must

Fig. 10. Frontal lifting of legs.

Fig. 11. Menu to create new movements.

Fig. 12. Principal menu.

separately be analysed in their three dimensions (A and B respectively). For example, the analysis of the x-vector is shown in Fig. 6, considering that the exercises performed by the patient are not developed with the same duration, being a disadvantage when using Euclidean distances. Therefore, an accumulated matrix is proposed:

$$D(n, m) = DTW(A(1{:}\ n), B(1{:}\ m)) \tag{4}$$

The expression A being vectors in three dimensions is given by $A(3{:}\ \text{n})$, thus

Fig. 13. Database manager.

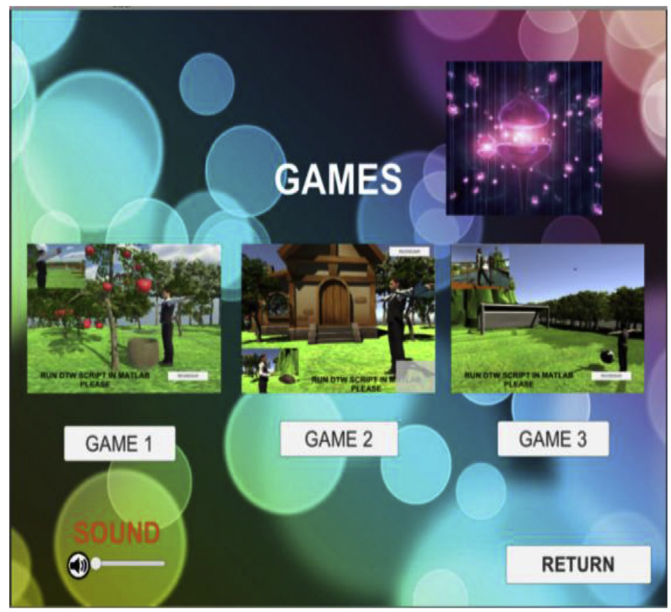

Fig. 14. Rehabilitation games Menu.

Fig. 15. Correct execution of arm stretching.

$$A(3{:}\ n) = [(x1, y1, z1),\ (x2, y2, z2),\ \ldots..(x_n, y_n, z_n)],\ \forall\ n\ \in [3, n]$$

$$B(3{:}\ n) = [(x1, y1, z1),\ (x2, y2, z2),\ \ldots..(x_m, y_m, z_m)],\ \forall\ n\ \in [3, m]$$

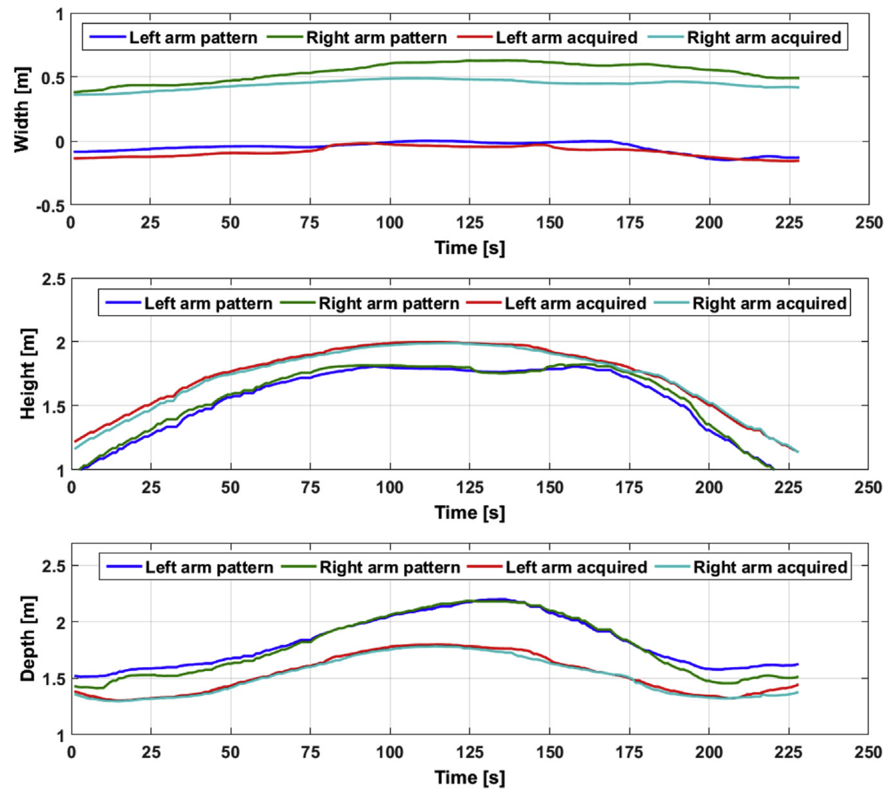

Fig. 16. Data acquired and plotted in mathematical software.

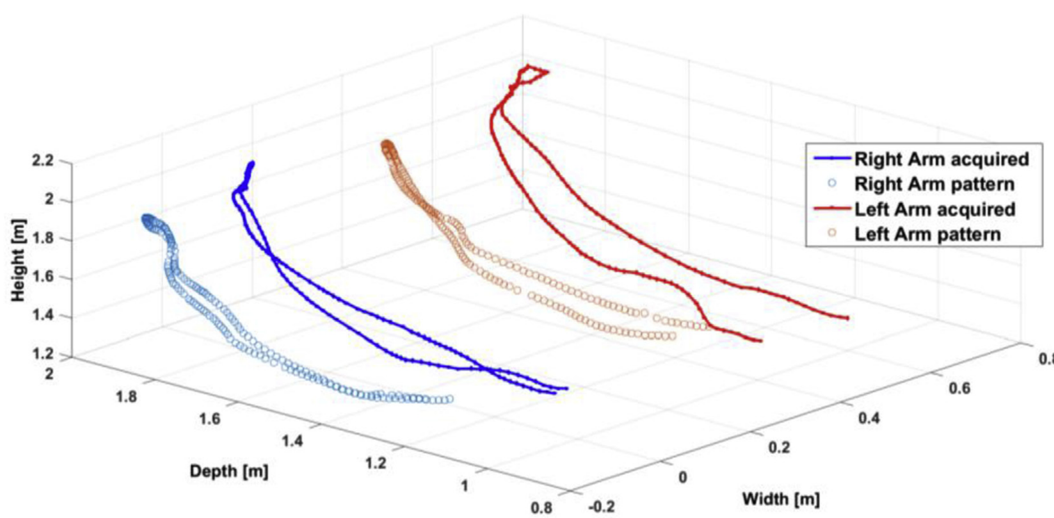

Fig. 17. Movements acquired and compared with the information stored in the database.

Thus, the matrix has the expression:

$$D(n, m) = \min\{D(n-1, m-1), D(n-1, m), D(n, m-1)\} + c(x_n, y_m) \quad (5)$$

Therefore, the calculation of the DTW algorithm will be obtained from the expression $DTW(A, B) = D(n, m)$. The expression (6) determines the average distance of the matrix of accumulated distances of each of the vectors analysed:

$$d(A, B) = \sqrt{\sum_{i=1}^{n,m} (X_i, Y_i, Z_i)^2} \quad (6)$$

As can be seen in Fig. 7, the proposed algorithm determines the temporal alignment of the sequences regardless of the amount of samples the sequences present.

7. Experimental results

The experimental results are split into three sections, which include the development of the proposed application, experimental tests with end-users, and the validation of the presented method. The development of the interface shows the main windows of the entire application, while the experimental tests show relevant results when executing the application with real users, and finally, the application is validated through answers based on a questionnaire provided to users and specialists.

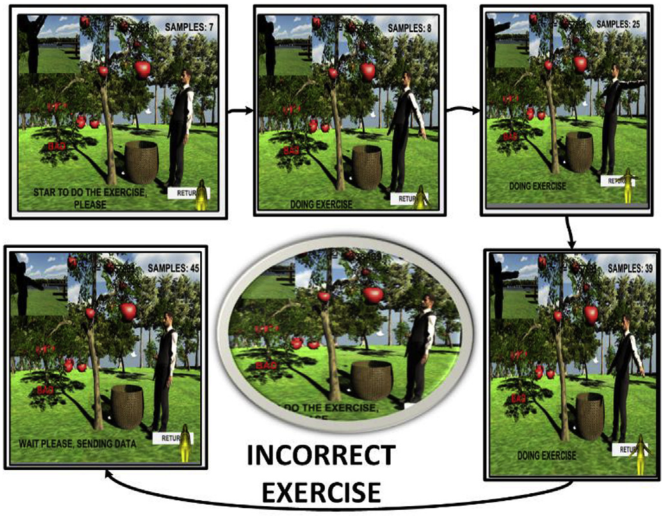

Fig. 18. Incorrect execution of arms extension.

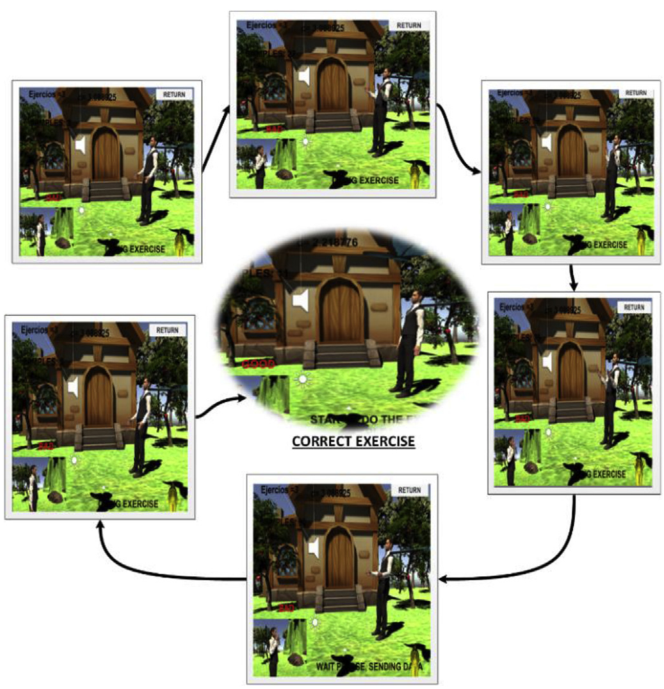

Fig. 19. Execution of arm supination task.

7.1. Game interface

The system implements four rehabilitation games. Three of them are based on information stored in a database, which is used to contrast the sequence of new movements with a sequence of pattern movements. In all games, the main window is displayed containing the avatar, a small window which indicates the routine that the patient should execute, and a third small window that shows the current position of the patient tracked by the Kinect sensor. The first corresponds to a routine for fruit collection, in which the correct elongation of arms is evaluated to reach an object programmed in the virtual interface (Fig. 8). The second involves the supination of arms, evaluating the bending of arms (Fig. 9). The third evaluates exercises performed with the lower extremities simulating the kick of a soccer ball (Fig. 10). Finally, the latter environment is a manager for configurable movements, with which new movement routines can be generated, which can be stored in a database to serve as standard sequences (Fig. 11).

Each of the games can be accessed by a menu presented at the beginning of the application (Fig. 12). The menu allows access to the configuration of the patient's personal data (Fig. 13), to the generation of a new database and to the games (Fig. 14).

7.2. Experimental tests

In order to obtain experimental information about the rehabilitation framework, two exercises are taken as a basis. The *first one* is the raising routine of arms to obtain a simulated fruit. The exercise is performed in a satisfactory manner when the patient starts with an arm position on the hip and gradually raises them to the full elevation, stretching completely the arms, as shown in Fig. 15.

For satisfactory execution, the movements of the patient may be out of phase in time, but with restriction conditions in the movement of the arms, e.g. just raise an arm, raise them individually, not lift them fully, or lift one completely and bend the other. The execution evaluation is carried out by the mathematical software, which relates both data frames, executes the DTW algorithm and obtains results which determine the validity of the exercise. Fig. 16 presents the data acquired on each of the axes (width, height, and depth in meters) in the mathematical software, while Fig. 17 shows the movements performed in a three-dimensional space.

In the case of Fig. 17, the task execution is correctly developed. However, to verify the functioning of the developed framework, Fig. 18 shows the response message if the exercise is completed unsatisfactorily.

The *second experiment exercise* is based on arm supination, where the goal of the task is to begin posture with the hands in proximity to the hip. The procedure is then to bend the elbows and maintain the arm motionless, raise the forearms to shoulder height, and return to the starting position. Fig. 19 presents a sequence of movements that validate the execution of the exercise, since the database contains a similar sequence but with mismatches in the data vectors. The validation is performed in the mathematical software, which acquires the new input information, executes the matching algorithm and returns a result dependent on the similarity of comparison between the two sequences. Fig. 20 shows the vector resulting from aligning a pair of sequences corresponding to the y-axis movements (height), denoting the application of the DTW algorithm.

7.3. Validation of the application

The rehabilitation framework for patients by means of virtual reality feedback was tested with a group of 5 users with mild stroke. On average, the patients are 42 years of age, the same ones who have followed rehabilitation treatments with a period no longer than two years and have a different level of disability between each of them. It is necessary to consider which patients have had a slight prior interaction with the type of technologies used in the proposed recovery method, requiring a general introduction in the way the equipment is used. In this regard, the system includes a computer with satisfactory processing characteristics (Intel I7 ninth-generation processor, NVIDIA® GeForce® GTX 1080 video card, 16 GB RAM, Windows 10 64-bit operating system), a Kinect sensor, sound sources, and virtual reality glasses, where the Oculus Rift helmet is the only device with which the patient interacts. The adequate interaction with the VR environments and with the entire system is guaranteed by the high image refresh rate (60 fps), also considering which the tests have been performed in a location close to a rehabilitation center.

Remark 1. By not working with invasive devices or instruments, the experiments do not require a clinical study, but only the suggestion of exercises given by the specialists. The profile of the two specialists (physical therapists) meets the requirements for the evaluation of the application, where one shows that he/she has worked with similar

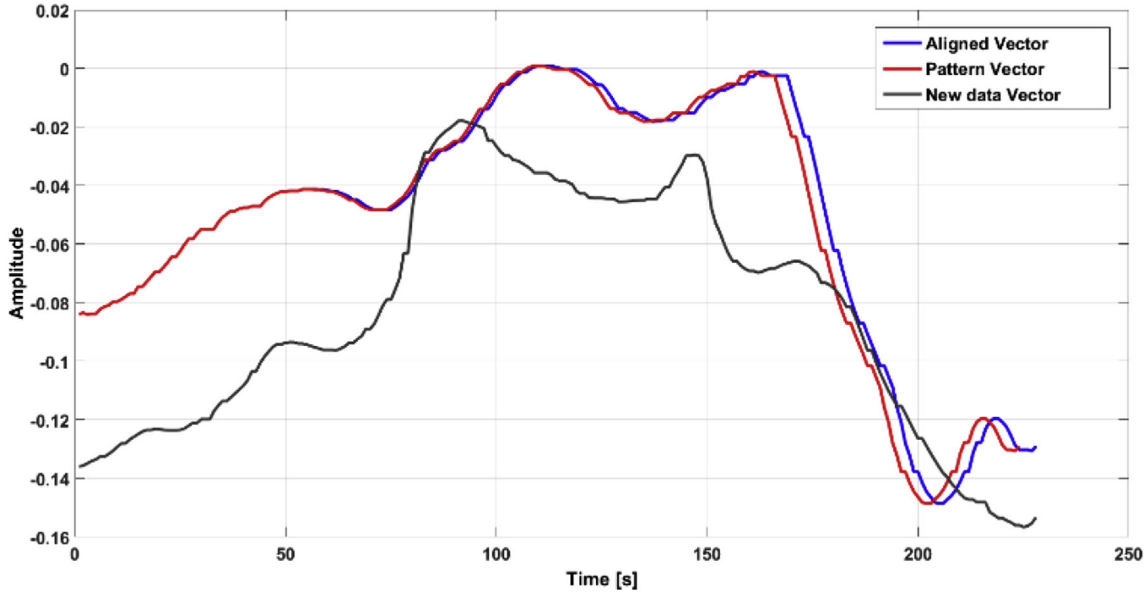

Fig. 20. Application of the DTW algorithm for the alignment of the signals in the arm supination task.

Table 1
Questions to evaluate the usability of the framework.

QUESTIONS
Qp1. I am familiar with the handling of devices that facilitate the immersion in virtual environments
Qp2. Handling virtual environments is relatively easy.
Qp3. The execution of the interface is simple and intuitive.
Qp4. The limitations given by external noise (light, depth) are imperceptible.
Qp5. The equipment used does not cause any discomfort.
Qd1. Patients are enthusiastic about these types of rehabilitation options.
Qd2. The system facilitates obtaining information on the progress of the patient's treatment
Qd3. The configuration of new routines allows increasing the complexity of tasks to accelerate the recovery of the patient
Qd4. The system is sufficiently robust to determine slight missteps in the sequences.
Qd5. The system can be readily implemented in institutions dealing with this disease.

proposals but not at the national rehabilitation centres.

To determine the simplicity of operation of the developed application, a group of questions (Table 1) was answered by the physical therapists (Qd) and the affected people (Qp) by the disease type, where a factor of 10 demonstrates positive responses and a factor of zero demonstrates negative responses (Fig. 21).

Consequently, this framework seems to be very user-friendly for both the patient and the attending therapist.

8. Discussion and conclusions

This work presents the development of an application which includes a set of games based on virtual reality, proposing the execution of movements of upper and lower extremities in order to recover the motor properties after stroke. To validate the correct execution of exercises, a Kinect v2 sensor is incorporated into the system to track the

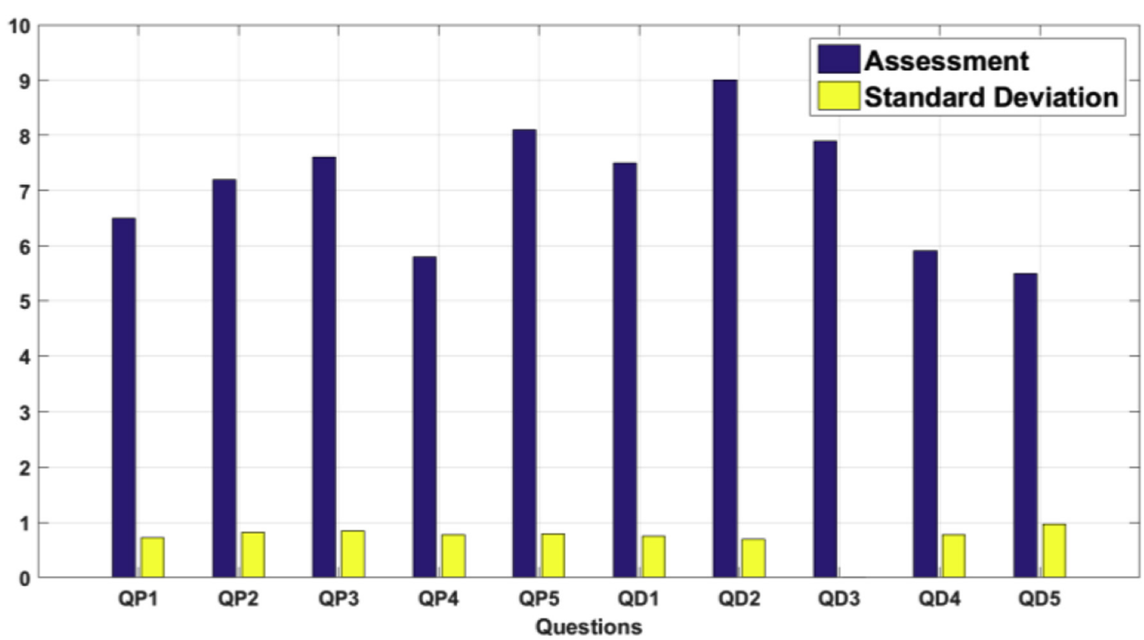

Fig. 21. Questions results.

extremities' movements and validate the tasks by means of a DTW algorithm. Through the DTW alignment algorithm applied in the system, a new sequence of movements similar to the pre-recorded ones can yield a satisfactory result, improving and accelerating the treatment of people who have suffered a mild stroke. Although the proposed system is developed in a place close to a rehabilitation center, the support given by the specialists is considered in order to include appropriate rehabilitation exercises. The use of this type of technology increases motivation in the development of exercises, where interaction with digitally reconstructed scenarios generates a level of immersion, necessary to retain the attention of the user and influence them to continue with the tasks of recovery. The qualification obtained as user feedback demonstrates the usability of the application, where the standard deviation shows a low tendency of variation between each respondent. In addition, the experimental results demonstrate the feasibility and ease of use of the rehabilitation system. Finally, future work can be proposed with the aim of including more users, with moderate conditions, and in a home environment without specialized support in order to verify the viability of the self-rehabilitation system.

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