KinesiOS: A Telerehabilitation and Functional Analysis System for Post-Stroke Physical Rehabilitation Therapies?

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Abstract. The stroke (also known as a Cerebrovascular Accident) is one of the medical conditions that most kills and incapacitates people in the world, affecting men, women and children of many different age brackets. Studies have been presented in recent years addressing the use of systems for motion capture in post stroke rehabilitation, showing that these tools could be just as efficient as the more traditional methods. In this study, we shall present KinesiOS, a system for telerehabilitation and recognition of movements for the motor and neurofunctional assessment of patients who are undergoing rehabilitation. The system tracks the joints in the human body based on their respective spatial coordinates, and then using the obtained data to construct a guide to movements in the form of a virtual skeleton, while measuring the amplitude of the movements (also known as a Range of Motion) within a certain motor action and showing the results in real time. The tracking of the joints is carried out using a Microsoft Kinect® sensor v2, while data processing, we used the C# programming language. We created the visualizations using the Windows Presentation Foundation® technology, and the data was saved in a cloud structure using the MongoDB® database. Preliminary tests performed on six healthy volunteers showed the efficiency of the system for the calculation of amplitude of movements, enabling data analysis in real time and through telemonitoring. KinesiOS is an alternative tool, portable and low-cost, compared with the traditional systems based on tracking of joints.

Keywords: Telerehabilitation · Motion capture · Kinect v2

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1 Introduction

A stroke, or Cerebrovascular Accident (CVA), is a neurological disorder caused by the interruption of blood supply to the brain, which occurs after either a blockage or a bursting of a blood vessel. This means that oxygen and nutrients that would normally be transported to the brain are suppressed, causing damage to brain tissue, which could bring about cognitive, sensory and/or motor sequelae in the patient [1].

Data released by the World Stroke Organization [2] suggest that 13.7 million people suffer a stroke every year in the world. Out of these, some 5.5 million die as a result, while another 5 million are left with some kind of handicap, which may persist for the rest of their lives.

According to Gillen and Nilsen [3], sessions of physiotherapy and occupational therapy are essential within the process of rehabilitation of patients, as they help the strengthening of the muscles and joints that may have suffered lesions because of the diseases, and increase the chance of recovery, with the partial or total reestablishment of the individual's functional independence. Among the challenges faced by health professionals within the rehabilitation process, we have the difficulty to obtain accurate data about the progress of the patients, and also the monotony of the treatment sessions, which means that some patients undergoing rehabilitation either give up entirely or do not carry out the activities with due attention.

Due to this alarming data and the difficulties encountered, it becomes important to invest in new technologies to help the treatment of stroke. This study proposes the development of a new system for telerehabilitation, by the name of KinesiOS, in a move to help health professionals to make decisions regarding the treatment, as well as getting the patient involved in the execution of rehab activities.

2 Related Works

Brandão et al. [4] prepared a set of software packages for motion capture and virtual reality, aimed at motor and neurofunctional rehabilitation. Known as the Gesture Collection, one of the applications makes use of the Microsoft Kinect® v1 device to establish interactions between gestures of the lower limbs, meaning that the patient may make virtual navigation through cities as previously mapped by Google Street View®, using a stationary gear (simulation of a walk, but without any spatial movement). The application also allows gestural interaction based on the upper limbs, which makes it possible to put together a kind of jigsaw puzzle, with the virtual movement of the pieces with the hands, also allowing the professional to collect data regarding motor actions performed during therapy, helping the professional during diagnosis.

Virtualware's Virtual Rehab® [5] uses Kinect® v1 to track and capture patients' movements, allowing them to be immersed in a 3D environment and interact with the game. The professional defines the structure of the exercise

and the game provides visual cues to the patient, eliminating the problem of forgetting the correct way to perform the exercise. In addition, the system will record the execution of movements and provide feedback to the patient and the specialist on the correct or incorrect movements made.

This paper seeks to provide a cheap and simple alternative solution, compared with the traditional systems based on monitoring of joints, using Kinect® v2, a quicker and more accurate device than the previous version, also allowing the monitoring of new body regions, such as the movements of stretching and flexion of the spine, and tweezer movements using the thumbs and the middle fingers. Moreover, the KinesiOS system was devised in a way that would allow remote service, meaning that patient and specialist do not need to be in the same place for the execution of rehabilitation exercises, which is very positive in these days of social distancing, due to the Covid-19 pandemic.

3 General View of the System

The user, positioned at a horizontal distance between 1.8 m and 2.5 m from the input device (Kinect® sensor), carries out the exercises previously entered into the system by the therapist, or exercises related to conventional therapy. The input device, which stands at an altitude of between 0.6 m and 1.2 m (above the ground), monitors the user's joints and then sends the coordinates to the system. This project uses MVC[1] architecture, so data is received first by the Controller, where the information is calculated, and the amplitude of the movements between the segments is calculated. The data is then sent on to the Model, which saves the coordinates and the respective angles in a cloud database. When necessary, the Model recalls the information from the database and then sends this information to the Controller once again, using the coordinates and generating visual feedback to the user in real time, in the application's View.

The View of the application is the reproduction of data generated for the virtual skeletons which are two: one virtual skeleton in green, which makes use of the coordinates recorded by the health worker and that is a kind of reference guide for a certain type of exercise (to be carried out by the patient), and another in red, which shows the movements of the patient, as being carried out, in real time. Figure 1 llustrates the system overview.

4 Materials and Methods

The motion capture takes place through the Kinect® v2 device [6], with an RGB camera, a depth sensor, and a multi-array microphone. To perform the monitoring of joints, the use of markers is not necessary, as the Kinect® projects a grid of infrared dots throughout the space in front, and then captures the

[1] MVC (or Model, View and Controller) is a software architecture standard, used for the development of user interfaces, which separates the program logic into three interconnected layers.

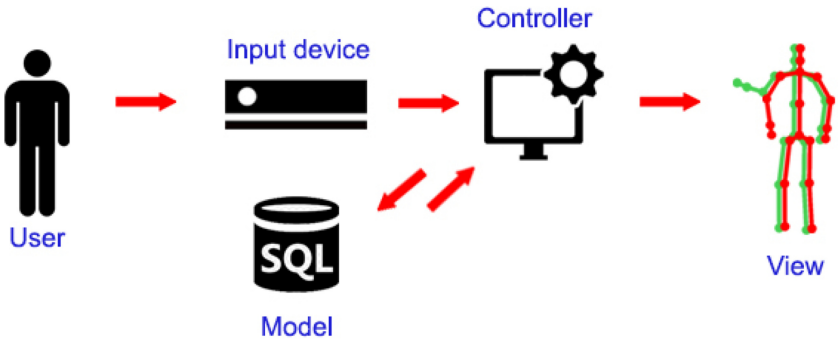

Fig. 1. KinesiOS system overview.

reflections of these points when they collide with the objects, calculating just how long each dot issued takes to be reflected back to the device, detecting joints and generating a flow of data at 30 frames per second.

Each frame has 25 lists of data used to identify the joints at a given point of reference in the 3D body. Each joint is represented by a list of coordinates, X, Y and Z, within the coordinate space of the camera, with X representing the horizontal distance, Y the vertical distance, and Z the depth of the joint in relation to the camera.

For the construction of the system, the C# programming language was used. This is the same language used for the development of the Software Development Kit (SDK) of the Kinect® v2, which ensures a greater compatibility with the device, and allows the use of Windows Presentation Foundation® (WPF) in the construction of layouts and viewings. This means that the development of a system with a modern, responsive and well usable design is now possible, thereby facilitating the use of virtual geometric forms, which shall be used for the construction of virtual skeletons [7].

The data harnessed and calculated by the system are sent to a MongoDB® database, a non-relational database aimed at documents and high performance, which is ideal to work with in this case because of the large volume of data to be generated by the system [8]. This database is available on the cloud, making it possible to access the information anywhere and at any time, requiring only that the professional is registered in the system.

4.1 System Features

The system is divided into two main modules, as shown in the flow chart in Fig. 2 the professional's module and the patient's module.

The professional's module is used by the health professional to record the exercises that shall be used by the patient during his or her rehabilitation sessions. The user must choose the capture plan, between coronal, sagittal and transversal; then select the viewing mode, which can either be 'in depth' or

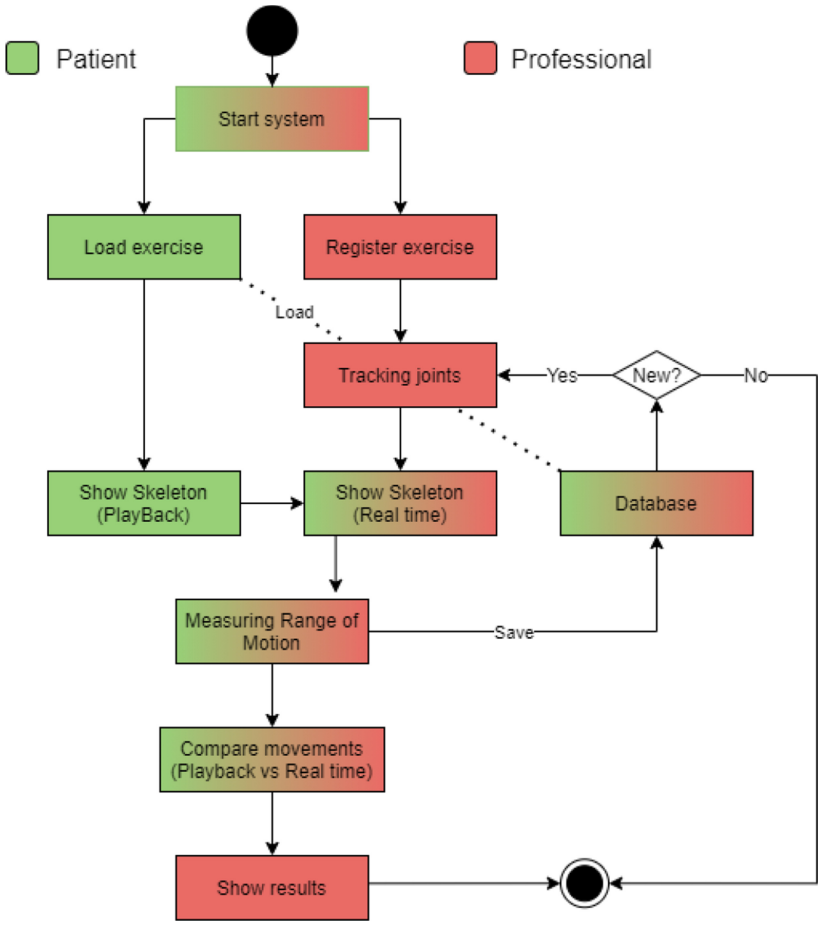

Fig. 2. KinesiOS system usage flow diagram.

'without video', the latter being to preserve the identity of the patient and also to avoid disclosure of the place where the recording is being carried out. Finally, the joints to be monitored shall then be selected. The virtual skeleton and the amplitude of the movements between joints are shown in real time, with the joints being represented by an object shaped like an Ellipse, that shall receive the coordinates X, Y and Z from the list that represents the joint being monitored. As this list is constantly being updated with the new position of the joint as the user moves around, the Ellipse also moves according to the new coordinates as received, being a kind of guide for the identification of the position of the joint. Figure 3(A) presents an example of the monitoring of the user's right shoulder, in real time of execution.

Whenever two interconnected joints, like the right shoulder and the right elbow, are selected for exhibition, there is a need to draw in the line that

connects the two limbs, and for this an object of the Line type is used, having its coordinates X1-Y1 and X2-Y2 connected to the Ellipses of the monitored limbs, thereby giving rise to the virtual skeleton, as shown in Fig. 3(B).

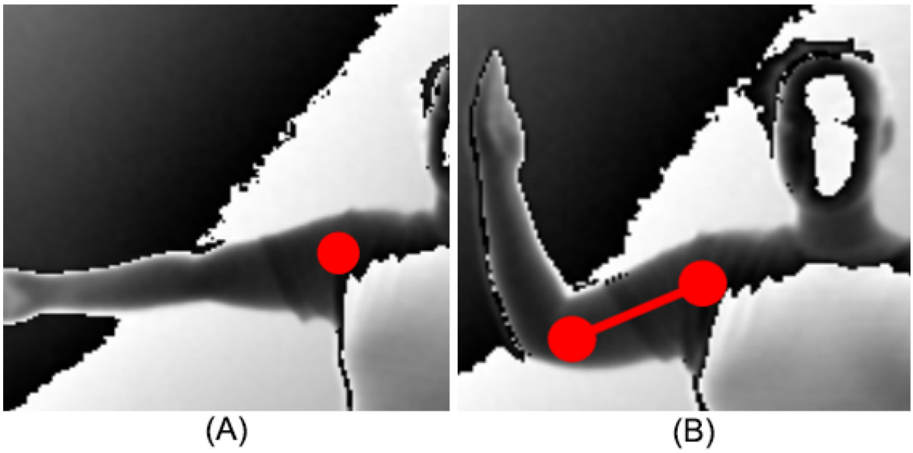

Fig. 3. Tracking spatial coordinates of the user's shoulder and right elbow.

To record the exercise, it shall suffice to select the option 'Start Recording', and then the system shall start saving the X, Y and Z coordinates and calculating the amplitude of movement of all the limbs visible on the screen, recording the information in a database in the cloud. Later on, the user may view or exclude the exercises through the 'View Recording' option. The patient's module is very similar to the professional's model, the difference being that the professional person has the option of showing the virtual skeleton as previously recorded together with the virtual skeleton of the patient, generated in real time. This shall be a guide and shall help the recovering individual with the correct execution of the movement.

4.2 Calculation of the Amplitude of Movement

Amplitude of movement (also known as a Range of Motion or ROM) is a term used to define the degree of stretching or flexion that a joint manages to reach in one or more movement plans (depending on the type of joint to be studied). The traditional method used to assess the amplitude of a movement is called goniometry, and it is normally applied by using a goniometer, a kind of ruler with two arms centrally joined by an axis, which allows the movement of the same. In the center of the device there is an inscription in degrees and as the extremities of the joint move, markings parallel to the inscriptions indicate a range of motion.

For the calculation of this amplitude of movement, the KinesiOS system there is always consideration of three joints in the body as monitored by Kinect®. For example, to calculate the amplitude of movement of the elbow, the parameter used is a vector with the position of the elbow; of the joint distal to it, which is the wrist; and the joint proximal to it, which is the shoulder. The coordinates being given, then the distance between the points is calculated, using the formula:

$$ShoulderElbow = Elbow(X_E, Y_E, Z_E) - Shoulder(X_S, Y_S, Z_S) \quad (1)$$

$$ElbowWrist = Wrist(X_W, Y_W, Z_W) - Elbow(X_E, Y_E, Z_E) \quad (2)$$

After the vector of spatial coordinates between the joints is processed, then the amplitude of movement can be found by applying the cosine law [9], as highlighted below:

$$Cos\theta = (ShoulderElbow * ElbowWrist)/(|ShoulderElbow| * |ElbowWrist|) \quad (3)$$

$$\theta = Cos^{-1}(Cos\theta) \quad (4)$$

Figure 4 illustrates the calculation of the right arm angle.

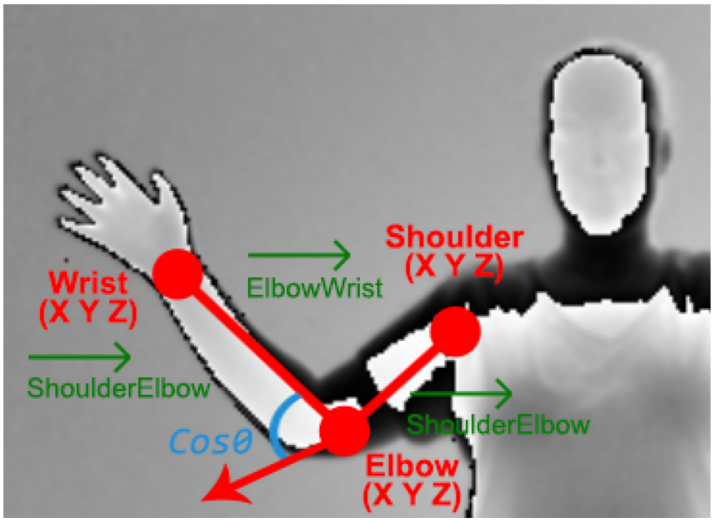

Fig. 4. Calculation of the range of motion of the right arm.

4.3 Telerehabilitation

Telerehabilitation [10] is the delivery of rehabilitation services through telecommunication networks or through the Internet, allowing the professionals to interact with the patients from a remote location, appraising and overseeing the exercises related to rehabilitation therapy. Among the advantages of this technology, we would like to highlight the fact that the patient does not have to go to the rehabilitation centre, and also the possibility that these exercises can be carried out in a residential environment, which could be a factor of motivation and is also a powerful tool at these times when social coexistence is severely restricted (social distancing due to the pandemic of Covid-19).

The system as here proposed uses an online database structure (in the cloud), on servers that can be accessed from remote locations and that receive the data as generated by the patient in real time, making it possible to transfer this data to a virtual skeleton, which reproduces the exercise that the patient is carrying out.

The professional and the patient may communicate by audio, as the system uses a special technology known as 'sockets', which sets up a link between the machines (professional and patient), thus allowing the sending and receiving of audio materials. The only need is for the computers to have microphones and speakers installed [11]. This means that the professional is able to guide and correct the movements made by the patient. In the same way, the patient can solve any doubts that may arise during the rehab sessions. Figure 5 shows the main screen of the KinesiOS system.

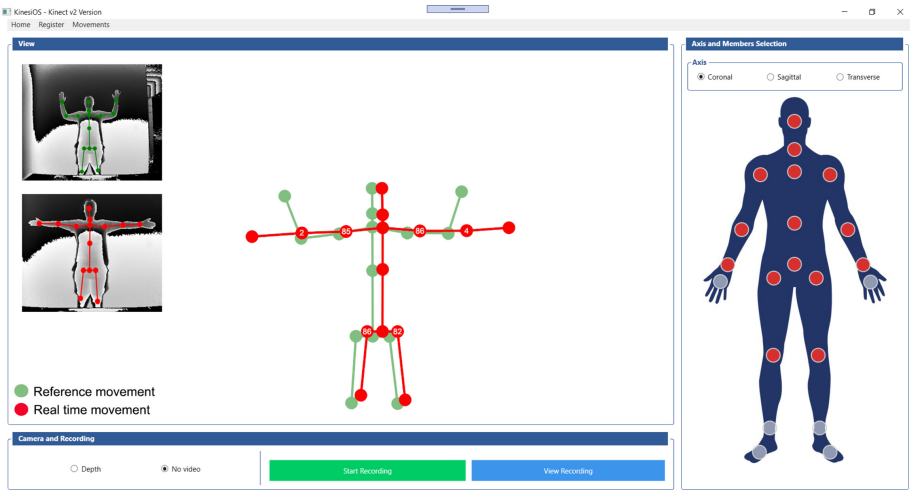

Fig. 5. Motion capture screen of the KinesiOS system. The reference movement is displayed in a green skeleton, while the skeleton in red represents the movement performed in real time by the user. (Color figure online)

4.4 Appraisal of the Exercise

To establish if an exercise has been correctly performed, two different approaches are used: identification on a frame-by-frame basis, and identification using key frames. In frame-by-frame identification, the coordinates of the user's joints are stored frame by frame, from the initial to the final position. This means that, during the execution of the movements, the angles of the joints are compared with frames from the reference exercise.

In the case of identification based on key frames, the user is advised to make the whole movement, but only the initial, middle, and end frames are considered for the appraisal. In both approaches, the professional person gets visual feedback in real time and in the form of a line graph, so that he or she may analyse the movements made, and provide guidance to the patient regarding possible corrections of posture. The execution of the exercise shall be taken as correct if the results regarding the amplitude of movements of the patient's limbs are the same as those of the reference exercise, or if they lie within the percentage of tolerable error, which is set by the professional, according to the phase of the therapy or the extent of motor impairment shown by the patient.

Apart from visual feedback, if necessary, the professional may also export the coordinates and the calculations of amplitude for all limbs monitored, to a file in XLS format, thereby permitting the use of the data in external tools, for the construction of graphs and statistical analyses.

5 Preliminary Results and Discussion

To validate the system, preliminary tests were carried out, with six participants aged between 25 and 60, men and women of different heights and weights, without any limitations on performing the chosen activities. The test sessions were carried out in a controlled environment, well lit, and without any objects blocking the field of vision of the input device.

The flow of the test comprised demonstration, training, and execution.

- Demonstration: The operation of the system is presented to the users, who are instructed about how to interact with the system;
- Training: The execution of the exercises is shown to the users; and
- Execution: The users carry out the exercises again, without any kind of help.

Figure 6 shows the results obtained on carrying out exercises for abduction and adduction of the left shoulder, where the movement starts with the arm close to the body (anatomic position) and ends with the arm at shoulder height and parallel to the ground. The initial amplitude of all users was close to 20°, while the final amplitude was around 100°, which is within the parameters considered as correct, when compared to the traditional goniometer calculation method [12].

For a second test, the data regarding amplitude of movement of a user during interaction with an application was collected, to allow the pieces of a virtual jigsaw to be put together, based on interaction with the upper limbs.

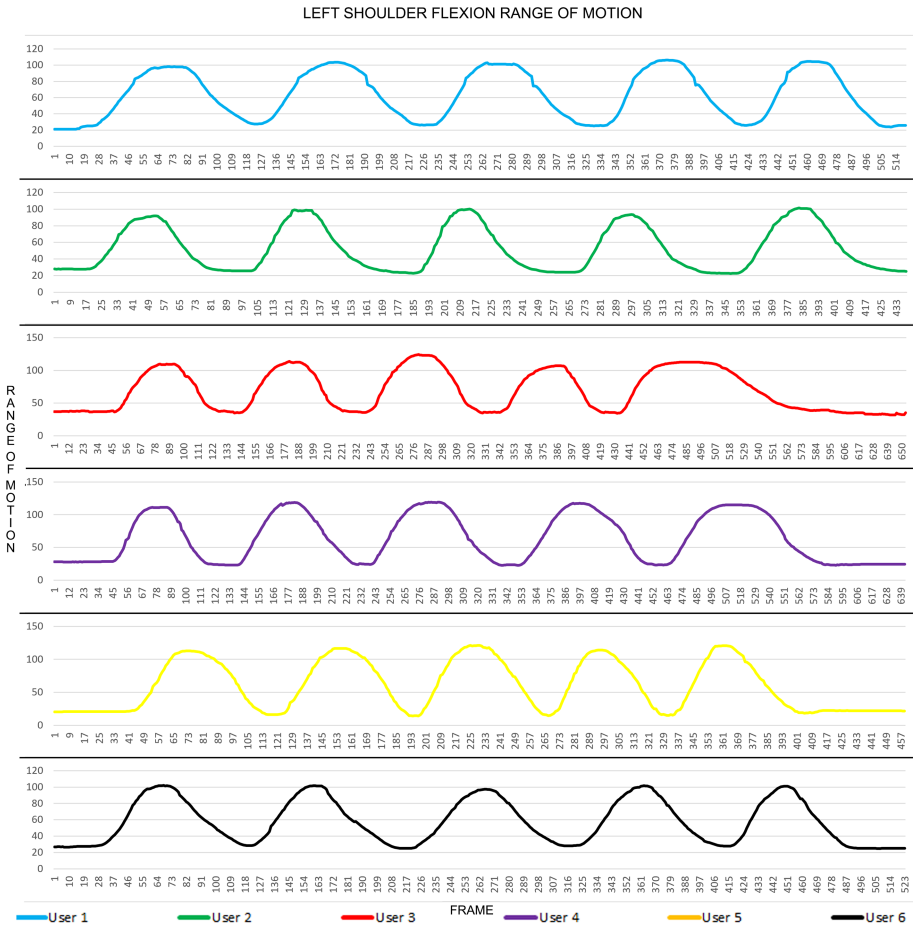

Fig. 6. Results of the amplitude of movements the left shoulder when performing the flexion exercise.

The exercise carried out when assembling this jigsaw needs movements of horizontal abduction and adduction of the right arm, and data of amplitude of movement were recorded, in relation to the right shoulder joint. In the graph highlighted in Fig. 7 one can identify the very moment when each piece of the jigsaw is placed. The pieces were separated in twelve parts, initially positioned on the left side of the application's interface, so they were controlled based on a virtual right hand (that, after monitoring of gestures, responded to the movements of the user's real hand).

This means that when the user made a move of horizontal abduction with the right arm (to pick up one of the pieces), the amplitude of movement was larger; when the user made a movement of horizontal adduction (to fit the piece in the grid) then the amplitude of movement was much less, as the reference

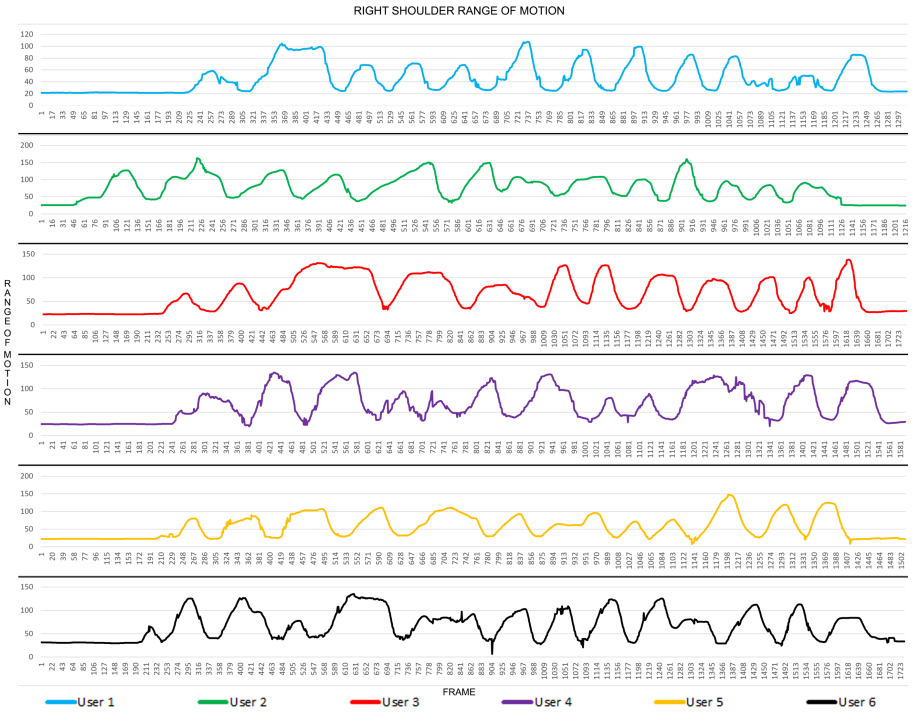

Fig. 7. Results of the amplitude of movements the right shoulder when assembling a virtual puzzle.

point for the start of calculation of the amplitude of movement was positioned on the midline of the user's body.

6 Conclusions

Applications for motion capture based on devices with infrared sensors, without markers, have been very widely used in supporting rehabilitation of patients who have had a stroke. However, the process of acknowledgement is still highly complex, especially when all the frames of a given exercise need analysis, as there is a need for a high processing cost, so that results may be generated in real time.

In this work, we seek to help the patient correct his or her own posture (bodily awareness) with the visual feedback given in real time, and supply data that could help the professional in application of the appropriate treatment, either in local or remote environment. Initial tests with healthy users were successfully conducted, showing that the application is effective, simple to use, and flexible, as it adjusts itself automatically to anatomic structures of various sizes and low costs, which makes the project feasible.

The following stages of the project shall include tests with more complex movements, also seeking to assess whether the results presented shall continue to be consistent, and if they shall allow the measurement of the progress of patients. There shall also be an assessment of how the system behaves in different environments, with different lighting, objects on the scene, and movements with occlusion of limbs, in order to gauge the limitations of the application. In addition, other types of feedback in real time, such as the speed of movement and the detection of gestures, can be implemented to give the professional more information, supporting the professional in making decisions.

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