Kinect-based application for progress monitoring of the stroke patients

Sofija Spasojević, Nela V. Ilić, Aleksandar Rodić and José Santos-Victor

***Abstract*—In this paper, we present a new approach for monitoring of patients during recovery after stroke. We propose quantitative measurements to characterize patients' movements. The focus is on the large range upper body movements acquired using Kinect device. Finally, we develop a software application for visualization and interpretation of the collected sensor data and calculated measurements. The application is intended to support the clinical evaluations by medical doctors and to store the patients' data over time. We record patients' scores during their scheduled rehabilitation sessions. Based on the collected scores, we build the personal profile for each patient that gives insight into the movement performance over time.**

***Index Terms*—Kinect, movement analysis, stroke, rehabilitation.**

I. INTRODUCTION

TRADITIONAL rehabilitation therapy is often long-term, tiresome and non-motivational process. On the other side, evaluation of patients' state by medical doctors is based on the qualitative clinical scales that are susceptible to subjective conclusions. Sometimes, clinical scales are not informative enough to describe the true patients' condition. Consequently, there is a need for introducing new techniques into rehabilitation procedures towards quantitative measurements of patients' performance. Novel sensory techniques can be used to support evaluations by doctors, as well as to encourage the patients during the treatments.

Our long-term goal is to develop a portable, low-cost rehabilitation system for neurological disorders, along with the approach for movement quantification. Additionally, we plan to improve the evaluation procedures during monitoring of patients' recovery. For this purpose, we design a software application for storing, visualization and interpretation of the patients' movement data during rehabilitation sessions.

The movement data acquisition is performed using the Kinect device. The set of upper body experimental exercises is defined by the medical domain specialist – physiatrist. Calculated quantitative measurements mainly result from the doctor's suggestions, and partially from properties of the sensor data. They are further integrated inside the developed software application and used as evidence of the patients' performance over time.

The remaining of the paper is structured as follows. Section II reviews the state of the art of general and Kinect-based techniques intended for rehabilitation in neurological disorders, with the special emphasis on rehabilitation after stroke. Section III explains the proposed approach and provides a brief summary of the Kinect device characteristics. Section IV describes the procedure of data acquisition and calculation of the quantitative measurements based on the movement data. Section V explains the software application design. Section VI summarizes the results of the proposed approach. In Section VII we draw the main conclusions and propose future extensions of this work.

II. RELATED WORK

Stroke is a neurodegenerative disorder, which causes impaired motor functions, mostly in the upper limbs. Recovering from stroke includes a lengthy rehabilitation procedure to recover the limb functionality. Evaluation of the patient's success during rehabilitation sessions is carried out using clinical scales (Fugl-Meyer [1]) that are prone to subjective rating and imprecise interpretation of patient's performance. The recent development of the affordable sensing technologies can potentially improve and support traditional evaluation techniques. The main benefits of the sensory systems would be relying on the objective approach and the possibility of home rehabilitation.

There are a lot of sensor-based systems used in rehabilitation for large-range upper body movement acquisition and later evaluation. Marker-based motion capture (mocap) systems [2] are often used for movement acquisition in general. They are well-known as extremely accurate systems, but also extremely costly. Other alternatives include the integration of different sensor types attached to the patient's body [3] and, more recently, low-cost marker-free mocap systems such as Kinect and Xtion [4]. The performance of lower-cost systems has been tested and shown to possess a satisfactory accuracy for the application in the rehabilitation therapy [5-8] and specifically for stroke rehabilitation applications [9]. While some examples of Kinect-based rehabilitation systems are described in [10-13], little attention has been devoted to the specific case of stroke [14-19].

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Authors in [14] use Kinect as a support device during Functional electrical stimulation (FES) in addition to surface electrodes, electro-goniometer and the data glove device. The study focuses on the small range arm/hand movements (reaching tasks). Kinect is intended for the calculation of the shoulder and elbow angle, while the wrist angle is measured with the electro-goniometer and the data glove. The movement performance evaluation is limited only to those joint angles (shoulder, elbow and wrist). The study [15] proposes the game-based concept to assist the physiotherapy after stroke. Kinect and Myo armband sensor are intended for tracking the patient's (player's) movements. The study lacks the proof of concept in the sense of the system validation through experiments with patients, as well as the signal processing, feature extraction and movement evaluation procedure behind the game interface. Authors in [16] perform the Kinect-based virtual reality training for motor functional recovery of upper limbs after subacute stroke. However, the evaluation after the training is based only on the clinical assessment tools (Fugl-Meyer and the Wolf Motor Function Test) and by observing the changes in activated brain regions (Functional magnetic resonance imaging – fMRI). Their conclusion is that the Kinect-based virtual reality training promotes the recovery of upper limb motor function after subacute stroke, however, the assessment of the patient's state does not include the Kinect data analysis. The authors in [17] evaluate the food-related tasks as activities of daily living (ADL), intended for post-stroke patients. They use Kinect to measure joint positions and angles of interest and inertial sensors to measure the acceleration. The system was tested only for healthy subjects, hence its further evaluation with the stroke patients is necessary. The authors in [18] develop the system based on the 3D vision using Kinect, accompanied by virtual environment, ergonometric signals and a humanoid (Nao) for stroke rehabilitation. The study proposes a large set of potential quantitative measurements, resulting from the kinematics of the upper limbs (joint rotations and distances between the joints), as well as the information based on the electromyography, goniometry, and inertial measurements. Nao robot represents the role of the therapist – to check how well the patients repeat the exercises and to encourage them during rehabilitation sessions. However, the study lacks the experimental verification with patients and evaluation of their performance based on the proposed set of quantitative measurements. The study [19] introduces the virtual rehabilitation system for stroke patients, composed of the Kinect device and haptic glove for tactile feedback. Kinect is used to track the upper limbs and to map the information to a virtual avatar. The authors provide their system with database and data visualization blocks for the further evaluations, but it is not highlighted in detail in the paper how the sensor data take part in the performance evaluations. The study requires further experiments with patients to confirm the eligibility of the proposed system for (home) rehabilitation applications.

III. PROPOSED APPROACH

General block scheme of the proposed approach for monitoring the stroke patients is illustrated in the Fig. 1. The first step is the upper body movement data acquisition using Kinect device, explained in detail in the next section. Collected data are first preprocessed in the sense of filtering and preliminary analysis for the further processing. The following step is the procedure of measurement calculation, described in the next section. Measurements are further integrated into the software application. The final step is the evaluation procedure relying on the designed application.

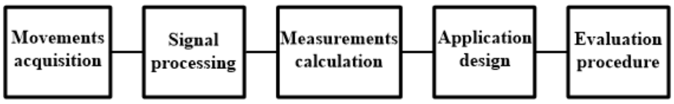

Fig. 1. Block scheme of the proposed approach

A. *Kinect device characteristics*

Kinect is the new generation device developed by Microsoft, which consists of a standard RGB camera and a 3D depth sensor (infrared sensor + infrared projector). It operates in a range of approximately 0.6m to 4m and can achieve up to 30 frames per second. Kinect has a built-in algorithm for human skeleton detection and tracking. The 3D coordinates of the characteristic skeleton joints are collected for every frame during the motion performance. The acquired Kinect data from our experiments consist of RGB video sequences and 3D positions of the fifteen skeleton joints (Figure 2).

IV. DATA ACQUISITION AND MEASUREMENTS CALCULATION

All subjects have been examined according to the protocol defined by a physiatrist. Experimental group is formed by three stroke patients. The subjects have performed two upper body movements well-known in the rehabilitation practice – shoulder flexion-extension (Fig. 2-a) and shoulder abduction-adduction (Fig. 2 - b). They have repeated the movements three times consecutively in both cases. The experimental set of movements will be extended in the future research.

Although we have collected the 3D coordinates of all 15 joints, in the further analysis we use the ones of interest for upper body movements (shoulder, elbow and hand joints).

a) b)

Fig. 2. Movements from the experimental protocol with collected joints: shoulder flexion-extension (a) and shoulder abduction-adduction (b)

A. Measurements calculation

Five quantitative measurements were calculated to characterize acquired upper body movements. Three of them are proposed in our previous research [20] and refer to the shoulder range of motion, movement speed and symmetry ratio. Two additional measurements are the vertical distance between the hands and elbow range of motion.

The range of motion (ROM) represents an angle of the movement relative to a specific body axis, which can be measured at various joints such as shoulder, elbow, knee, etc. In our case, we measure the evolution of the shoulder angle during the movement in relation to the longitudinal body axis. For a ROM measurement, we take the value of the angle in the final movement position. Fig. 3 illustrates the evolution of the elbow angle profiles during shoulder abduction-adduction movements. According to the movement definition, arms are stretched in the elbow during the whole movement. This means that elbow angle should be close to the 180°. Fig. 3 shows that for the healthy arm, elbow angle takes values in the range [160° - 175°], which is an expected result. On the other side, the affected arm has demonstrated significantly weaker performance. Elbow angle values for the affected arm are in the range [110° - 160°]. Such result suggests that the ROM of elbow angle is a good indicator of the movement performance and potential quantitative measurement of the difference between healthy and affected hand.

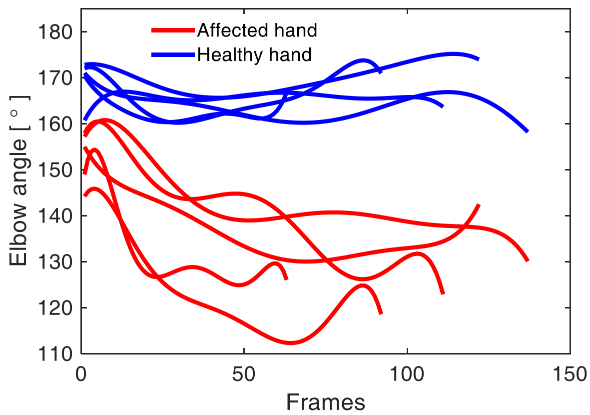

Fig. 3. Evolution of the elbow angle profiles during shoulder abduction-adduction movements.

We calculate the mean speed V during the movement (1). The total trajectory length (the numerator in (1)) is obtained by summing up the Euclidean distances (d) between the joint coordinates X_i (x_i, y_i, z_i) and X_{i-1} (x_{i-1}, y_{i-1}, z_{i-1}) for consecutive frames, i and i-1, during the movement. The time duration of the movement (the denominator in (1)) is computed based on the total number of frames (s and e denote respectively the first and last frame) and the frame rate, f=27 Hz.

$$V = \frac{\sum_{i=m}^{n} d(X_i, X_{i-1})}{(e-s+1)/f} \qquad (1)$$

Joint angle and angular velocity profiles can demonstrate the symmetry of the movements. In motor control, the symmetry ratio (SR) [21-24] is defined as the ratio between acceleration (t_{ACC}) and deceleration (t_{DEC}) times (obtained from the angular velocity profile), during one movement. An example of the angular velocity profile for shoulder angle, along with the calculation of the symmetry ratio (SR) is presented in Fig. 4. For normal movements, symmetry ratio has values around 1. In the case of the impaired movements, symmetry ratio has values significantly larger or smaller than 1, like it is shown in the Fig. 4.

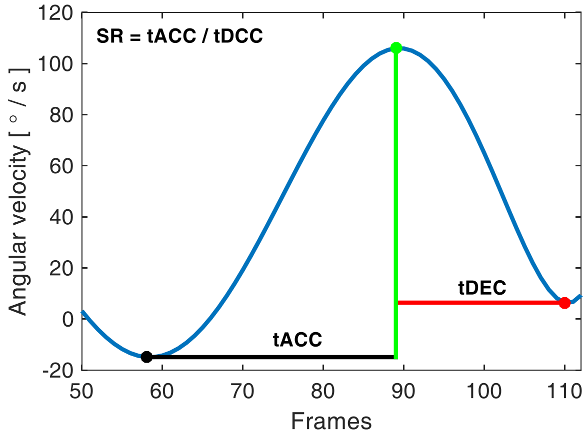

Fig. 4. Evolution of the shoulder angular velocity profiles during shoulder abduction movement and symmetry ratio calculation

Finally, we calculate the vertical distance between the hands relying on the left and right hand joint coordinates obtained directly from the Kinect.

V. Kinect-based application design

In the previous session, we have explained the procedures of the movement data acquisition and calculation of the quantitative measurements. In this section, we will reveal the content of the Kinect-based application. The application consists of the following units:

- List of the patients, along with the relevant clinical data (Fig. 5-a), such as stroke type, the time of the stroke occurrence, which hand is affected by the stroke, etc.
- List of the collected movements (Fig. 5-b);
- Visualization of the collected skeleton joints during the movement performance for each rehabilitation session (Fig. 5-c);
- List of the quantitative measurements calculated from the movements (Fig. 5-d), along with the graphical representation of their values across sessions (Fig. 6).

VI. Results

Kinect-based application, presented in the previous section, gives the insight into the patients' movement performance over time. Consequently, the application can be used by physiatrists as an additional tool to support their evaluation procedures. Fig. 6 illustrates the movement speed evolution for five consecutive recordings.

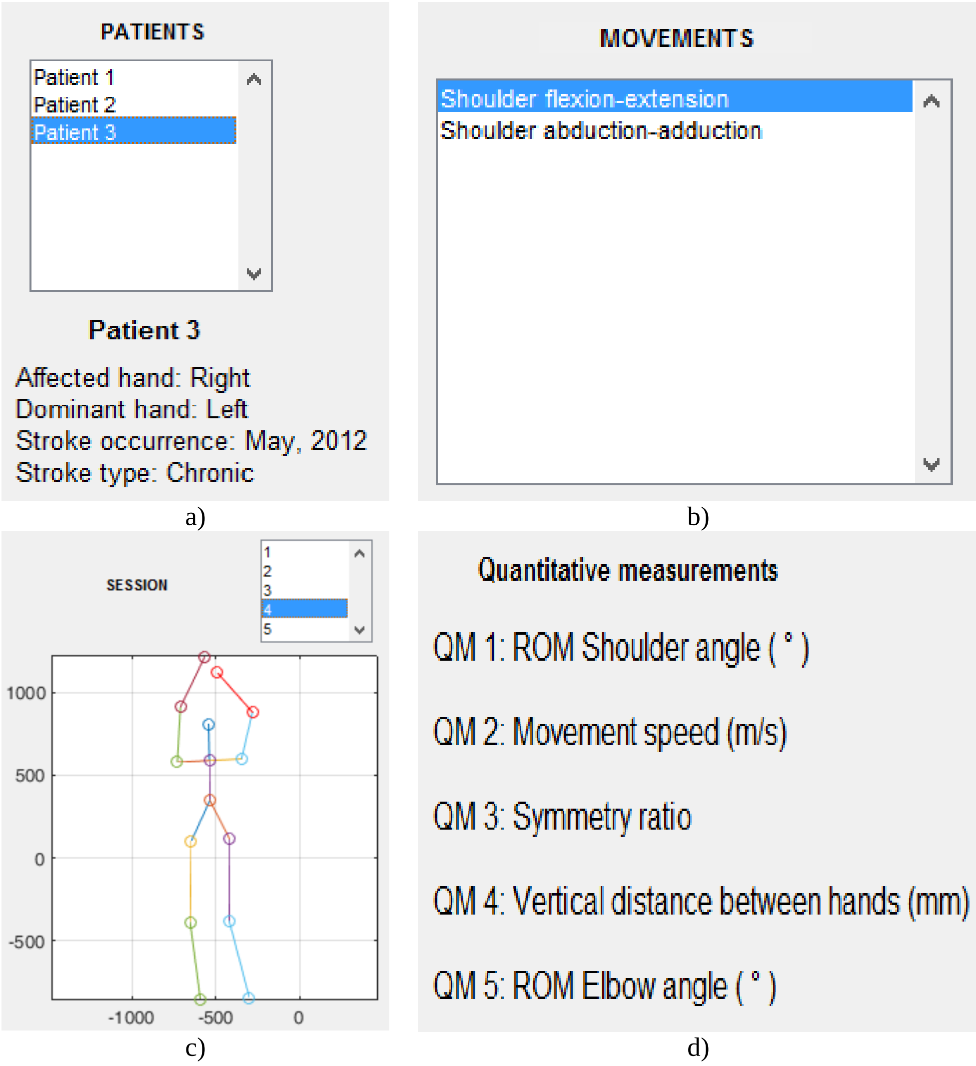

Fig. 5. Application units

The first four recordings are made between the one-week intervals, while the last recording is made one month after the fourth recording.

During the first four weeks, patient performed the training every day. The training consisted of the predefined set of exercises, designed by the physiatrist. After four weeks, the patient stopped the training and his performance is measured again after one month.

It can be seen that the movement speed has the similar values or slightly increases from one recording to another in the first four weeks during the training period. It reaches the maximum value in the fourth recording. However, in the last recording, the movement speed drops since the patient did not perform training during one month period. Such results strongly suggest the importance of the continuous training in stroke patients.

The results in the Fig. 6 are presented for the affected (right) arm and healthy (left) arm. Both parts of the shoulder abduction-adduction movement are taken into account – when arms go up and when arms go down. It can be seen that values of the movement speed are higher for the healthy arm in all four cases, as expected.

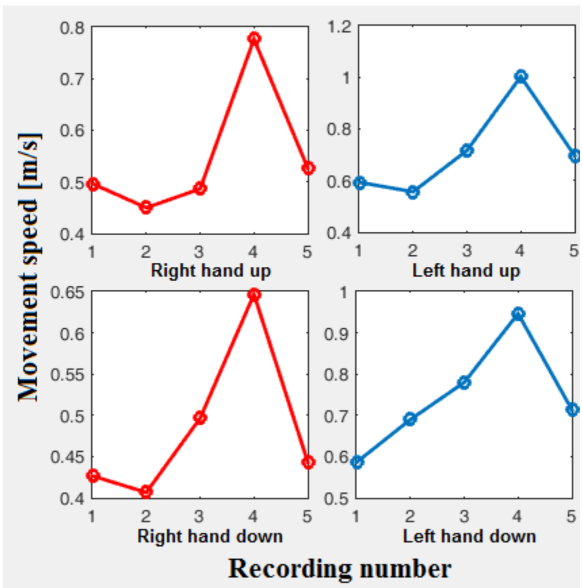

Fig. 6. Evolution of the movement speed across five rehabilitation sessions

VII. CONCLUSION

We have presented an approach for movement quantification, based on the measurements obtained from Kinect data. The focus is on the large range upper body movements, performed with both arms – affected and the healthy arm. We have designed an application for storing, visualization and interpretation of the collected data and quantitative movement measurements. The application is intended to support the clinical evaluations in the case of stroke patients.

Our results have demonstrated that our proposed measurements are relevant for the evaluation procedures in the case of stroke patients. The designed application is presented to one experienced physiatrist. From her point of view, the application is well organized, informative and equipped with meaningful content. She would use it to support clinical decisions about progress monitoring after stroke.

The following research will be primarily oriented to the extension of the data set. We plan to increase the number of subjects and the number of experimental movements towards the advancement and verification of the proposed approach. The future work will be focused on the extension of the approach in the sense of new sensor data and different groups of movements.

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