Kinect-based approach for upper body movement assessment in stroke

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Abstract. In this paper, we investigate how the objective movement assessment can support the clinical practice in the stroke treatment. The movement data are collected using vision-based, low-cost and marker-free Kinect sensor device. Sensor recordings are collected in the hospital settings for stroke outpatients with the supervision of medical doctors. We propose movement performance indicators, extracted from the sensor signals, to characterize the movements. The proposed approach for movement quantification is intended to support the clinical evaluations and to monitor the patients' state over time. The emphasis is on the verification of the proposed indicators and investigation of their importance for the stroke relevant clinical aspects.

Key words: Kinect, movement characterization, stroke, rehabilitation.

1 Introduction

Stroke is a leading cause of motor disability, the second most common cause of death in general [1], and the third, taking into account the countries of the developed world [2]. Approximately 80% of individuals that survive stroke suffer the neurological damage that leads to impairments of the motor functions, long-term disability and limited every-day activities [3]. Recovery after stroke requires a lengthy and slow rehabilitation procedure that usually includes the neurostimulation and motor training organized in clinical centers.

Evaluation of the patients' performance during rehabilitation sessions is based on the specially designed clinical scales such as Jebsen-Taylor [4] and Fugl-Meyer [5] scale. However, both clinical scales are prone to subjective and imprecise ratings and intended to be carried out by a trained physiatrist. Hence, there is a clear need for introducing new sensing/processing techniques into the clinical practice, capable to support the clinical evaluations in stoke by introducing the objective approach for the movement assessment.

In this paper, we investigate how the data from the low-cost, marker-free and portable Kinect sensor can support the rehabilitation therapy and evaluation procedures in stroke. We examine large range upper body movements of stroke patients. A set of experimental exercises is defined according to clinical protocols. The special emphasis is on the design of quantitative descriptors (so-called *Movement Performance Indicators*), extracted from the sensor data and proposed for the objective movement assessment. This paper presents the continuation of our previous research on Kinect-based approach for progress monitoring of the stroke patients [6]. The extension refers to the verification of the proposed indicators and investigation of their importance for the clinically relevant aspects.

2 Related work

Different types of sensor devices are used nowadays for the movement acquisition. Rough division addresses three main sensor groups: (i) vision-based with markers, (ii) vision-based without markers and (iii) wearable sensors.

The vision-based systems with markers (Marker based motion capture (MOCAP) systems) [7] involve the placement of the markers at particular body points and complex system of cameras for movement recording. Those systems deliver accurate measurements, but they are extremely costly and complex for use. In addition, MOCAP systems are not portable and the recordings need to be carried out in the specially designed environments. On the other side, low-cost and marker-free MOCAP systems such as the Kinect and Xtion [8] become very popular as a suitable alternative for expensive, complex and non-portable MOCAP systems. Using these new-generation devices, the movements can be acquired without markers, based on the inbuilt algorithms for skeleton tracking. The performance of lower-cost systems has been tested and the results report a satisfactory accuracy for the application in the rehabilitation therapy [9-12] and specifically in stroke rehabilitation [13]. However, their performance is quite lower in comparison to the advanced MOCAP systems and the readings are less robust to measurement noise. Still, they represent a good trade-off between the overall performance and cost. Some examples of Kinect-based rehabilitation systems are described in [14-17], but little attention has been devoted to the specific case of stroke [18-23].

The authors in [18] focus 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 [19] proposes the game-based concept – tracking the patient's movements using Kinect and armband sensor. The study lacks the system validation through experiments with patients, as well as the signal processing, feature extraction and movement evaluation procedure behind the game interface. The authors in [20] perform the Kinect-based virtual reality training for motor functional recovery of upper limbs after stroke. However, the evaluation after the training is based only on the clinical assessment tool. The authors in [21] evaluate the food-related tasks as activities of daily living (ADL), intended for post-stroke patients. They use Kinect to measure joint positions and angular values and inertial sensors to measure the acceleration. The system was tested only for healthy subjects. The authors in [22] 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, as well as the information based on the electromyography, goniometry, and inertial measurements. However, the study lacks the experimental verification with patients and evaluation of their performance based on the proposed set of quantitative measurements. The study [23] 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 study lacks the inclusion of sensor information in the performance evaluations and experimental verification based on the patients' data.

The overall conclusion is that the recent Kinect-based systems intended for stroke rehabilitation lack the following important aspects: (i) the movement evaluation procedure based on the sensor readings, (ii) experimental validation of the methods on patients' data and (iii) correlation of the proposed indicators with clinical scales.

3 The proposed system structure

The proposed system structure for the objective movement assessment from the Kinect sensor data is illustrated in Fig. 1. The first steps are the sensor calibration (placing the body in the particular position) and the movement data collection. As a second stage, the sensor signals are pre-processed using low-pass filters to reduce the measurement noise. A temporal segmentation algorithm is applied to the sensor signals since the movements are collected in the sequence, but each movement has to be analyzed separately.

The following step is the extraction of the movement performance indicators from the sensor signals. The indicators are clinically inspired and their design results from recommendations of medical domain experts. In the next steps, the proposed indicators are tested in terms of capability to support the relevant clinical aspects: (i) statistical investigation in terms of internal consistency and reliability; (ii) quantification of the differences between healthy and affected side and (iii) correlation with clinical (Fugl-Meyer) scale.

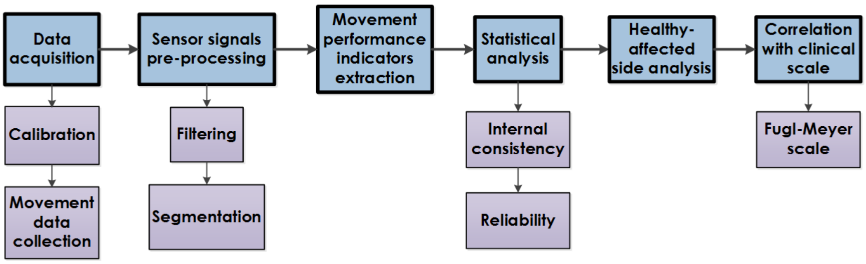


Fig. 1 The proposed system structure.

3.1 Sensor data acquisition

The experimental group consists of three stroke patients. All patients have been examined under the same conditions and they have performed five upper body movements, instructed by an experienced physiatrist. Illustration of the experimental movements is given in Fig. 2. The movement abbreviations listed in the caption of the Fig. 2 will be used from now on. The 3D coordinates of the characteristic skeleton joints are collected for every frame during the motion performance. Clinical measurements - Fugl-Meyer scale [5] are collected by an experienced physiatrist right before the sensor measurements.

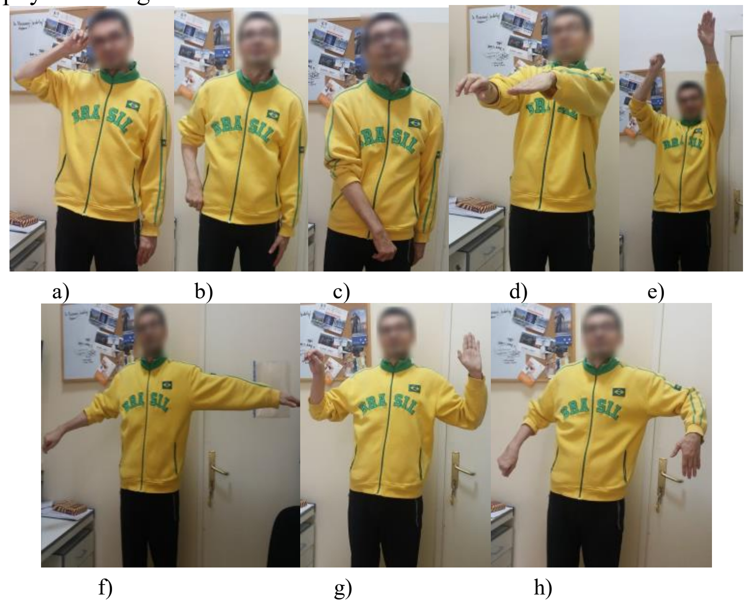
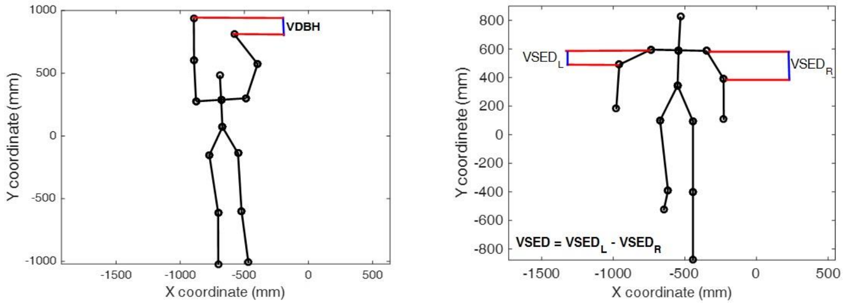


Fig. 2 **UB1:** Hand goes from the ear to the hip (same body side): (a) and (b); **UB2:** Hand goes from the ear to the hip (different body side - diagonal): (a) and (c); **UB3:** Shoulder flexion-extension: (d) and (e); **UB4:** Shoulder abduction-adduction: (f) and (e) and **UB5:** Elbow flexed at 90°: hands go up and down in shoulder joint (g) and (h)

4 Movement performance indicators

Relying on the collected sensor data, we have defined and extracted seven different movement performance indicators (**MPI**s). Those indicators refer to the elbow and shoulder angle (**A**) / range of motion (**ROM**), movement speed (**MS**), symmetry ratio (**SR**) among body sides and vertical distance (**VD**) between joints of interest – in our case between hands (**VDBH**, Fig. 3-a) and between elbow and shoulder (**VSED**, Fig. 3-b). The calculation of these indicators is explained in detail in our previous studies [6] and [24]. An example of the indicator calculation is illustrated in Fig. 3. The figure presents the patient's skeleton in the X-Y plane, along with the joint position data, collected from Kinect. The vertical distance (**VD**) between joints of interest is a clinically-based and stroke-relevant indicator. It is defined as the difference in y-coordinate of joints at the final movement position. In the case of regular movements, those differences should be close to zero, while in the case of the impaired movements at stroke patients, they become significant (Fig. 3).



a) b)

Fig. 3 Calculation of the **VD** between hands (**VDBH**) during the **UB4** movement (a) and **VD** between shoulder and elbow (**VSED**) during the **UB5** movement

The overview of the all extracted indicators across movements is presented in Table 1. The next step is the investigation of their capability to support the relevant clinical aspects, such as reliability, quantification of the differences between healthy and affected side and correlation with clinical Fugl-Meyer scale.

Table 1. Calculated Movement Performace Indicators across movements.

*Movement**	*Calculated Movement Performace Indicators (MPIs)*				
UB1	**ROM** shoulder	**MS**	**SR**		
UB2	**ROM** shoulder	**MS**	**SR**		
UB3	**ROM** shoulder	**MS**	**SR**	**VD** hands	**ROM** elbow
UB4	**ROM** shoulder	**MS**	**SR**	**VD** hands	**ROM** elbow
UB5	**VD** shoulder-elbow	**MS**	**SR**	**VD** hands	mean shoulder **A**

*Movement notation is taken from the caption of Fig. 2

5 Results

We have proposed a set of 21 MPIs in total to characterize five upper body movements (Table 1). In this section, we conduct the analysis of the properties of these MPIs, to identify their importance in terms of the technical and stroke-related clinical aspects: (i) statistical analysis of the sensor measurements and indicators, (ii) healthy-affected side analysis and (iii) correlation with clinical scale.

Internal consistency of the sensor measurements is assessed using Cronbach's alpha parameter [25]. Obtained Cronbach's alpha values across sensor data for all movements have values within the range [0.95 – 0.99]. Values close to one indicate the high consistency of the Kinect sensor measurements. In order to investigate the reliability of the extracted MPIs, the test-retest method for the reliability analysis [25] has been applied. The test-retest method correlates the scores across repeated tests and the reliability is assessed using *Intraclass correlation coefficient* (ICC) [25]. ICC values across all indicators are within the range [0.72 – 0.97], whereby the values closer to 1 indicate higher reliability.

The progress monitoring of the affected hand is the most important task in the rehabilitation after stroke. Another important concept is the performance comparison between the healthy and affected hand. In order to complete this task, the statistical comparison has been performed. The two-sided Wilcoxon rank sum test is applied between the MPI values obtained from the healthy and affected hand. The corresponding MPI is considered as relevant if it satisfies the following conditions: (i) the difference between the MPI values for the healthy and affected hand is statistically significant ($p<0.05$) and (ii) higher/lower MPI value in the case of healthy hand (depending on particular MPI). Only four upper body MPIs do not meet the statistical requirement in terms of the healthy-affected side analysis ($p > 0.05$). Those MPIs are **SR** for the movements **UB3**, **UB4** and **UB5** and **MS** for the **UB5** movement. Still, the remaining 17 MPIs turn out to be very relevant in distinguishing the performance of the healthy and affected hand, which is more than 80% of the proposed MPIs.

Table 2. Correlation between the proposed MPIs and Fugl-Meyer clinical scale expressed through the value of Pearson's correlation coefficient r

Movement	***ROM S****	***MS***	***SR***	***VDBH***	***VSED***	***ROM E****	***MSA****
UB1	0.67	0.61	-0.97	/	/	/	/
UB2	0.72	0.78	-0.79	/	/	/	/
UB3	0.74	0.75	-0.68	-0.90	/	0.69	/
UB4	0.98	0.54	-0.90	-0.90	/	0.96	/
UB5	/	0.80	-0.69	-0.96	-0.80	/	0.92

*ROM S – ROM shoulder; ROM E – ROM elbow; MSA – mean shoulder angle

In order to verify whether the proposed MPIs evaluate the patients' movement performance in the same manner as the official clinical scales, we investigate the correlation between the proposed indicators and clinical Fugl-Meyer scale. The values of the Fugl-Meyer scale are obtained as a result of a physiatrist's evaluation right before the sensor measurements. Correlations were calculated using *Pearson's correlation coefficient* r (takes values between -1 and 0 for negative correlation and between 0 and 1 for positive correlation), along with the p-value and confidence intervals. Values of r closer to -1 in the case of negative correlation and closer to 1 in the case of positive correlation indicate a better correlation between the variables. Absolute values of the Pearson's correlation coefficient r across all MPIs and tested movements are inside the range [0.54 - 0.98], Table 2. MPIs that have demonstrated very high correlation with the clinical scale ($0.80 < |r| < 1$) are **VD** (both between hands and elbow-shoulder) and **MSA**. The remaining MPIs have shown a high correlation only for particular movements (Table 2).

6 Conclusions

Statistical analysis of the repeated sensor measurements confirmed the internal consistency of the sensor measurements and high test-retest reliability of the extracted MPIs. The results of the healthy-affected side analysis report the high percentage of the MPIs relevant for assessing the differences between the healthy and affected hand - more than 80% (17 out of 21 MPIs). The correlation analysis emphasizes the good correlation between the proposed MPIs and clinical (Fugl-Meyer) scale (Table 2). Based on the obtained results, we conclude that the majority of our proposed MPIs can be included in the stroke treatment protocols and used to support the clinical evaluations by medical doctors.

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