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Proprioceptive Neuromuscular Facilitation Exercises of Upper Extremities Assessment Using Microsoft Kinect Sensor and Color Marker in a Virtual Reality Environment

M. Owlia, M. H. Azarsa, M. Khabbazan, A. Mirbagheri

***Abstract*—**Proprioceptive neuromuscular facilitation exercises are a series of stretching techniques that are commonly used in rehabilitation and exercise therapy. Assessment of these exercises for true maneuvering requires extensive experience in this field and could not be down with patients themselves. In this paper, we developed software that uses Microsoft Kinect sensor, a spherical color marker, and real-time image processing methods to evaluate patient's performance in generating true patterns of movements. The software also provides the patient with a visual feedback by showing his/her avatar in a Virtual Reality environment along with the correct path of moving hand, wrist and marker. Primary results during PNF exercise therapy of a patient in a room environment shows the ability of the system to identify any deviation of maneuvering path and direction of the hand from the one that has been performed by an expert physician.

***Keywords*—**Image processing, Microsoft Kinect, proprioceptive neuromuscular facilitation, upper extremities assessment, virtual reality.

I. Introduction

EXERCISE therapy is one of the most important, and highly effective component of a rehabilitation program in patients with joints pain and limited mobility [1]. Among the exercises, Proprioceptive Neuromuscular Facilitation (PNF) can be noted, a treatment prescribed frequently for orthopedic disorders. It is safe and time efficient, but more importantly, it can provide the patient with relatively quick gains in range of motion and motivate them to continue with the rehabilitation program [2]. Although in this type of exercise, the movements should be done with a specific pattern, with numerous joints and muscles involved in shaping it, the assessment of patient's progress and judgment about properly performing movement is done only through observation by the therapist, which can be too subjective [3]. Besides, most of the patients are not capable of self-assessing their performance; hence, they have to exercise under the supervision of a therapist. This will result in a less-sustained therapy procedure, as the rehabilitation process is limited to the time that the patient spends at the clinic. Therefore, it seems that an automated system for evaluating such movements, not only can be more accurate, but also will provide the patient with the necessary feedback while preforming the PNF exercises. Image processing might be the first thing that comes in mind. But 2D images do not suffice in measuring such movements: PNF exercises of the Upper Extremities should be done diagonally in the space and therefore *depth* changes in the moving segments of the image are important, yet they are not detectable. One device that has been considered in recent years for such purposes in the rehabilitation engineering field is the Microsoft Kinect Sensor (Microsoft® corporation, WA, USA). This inexpensive, relatively accurate depth sensing device is supplemented by a Software Development Kit that can provide programmers with 30 frames per second data on the 3D position of 20 joints for each of the two persons that may stand in front of it.

A number of studies have used the Kinect sensor for quantifying the physical postures in various settings and during different activities such as exercising, walking, and running [4]-[10]. Kim et al. used it for evaluating the performance of subjects in PNF. They implemented a machine learning algorithm and trained it with the joints position data from eight normal students, each of which performed the PNF stretching 30 times, to create software that is capable of detecting the correctness of exercises executed by a subject. They deemed the position of the joints adequate for this purpose [10], however, rotation of the forearm around its longitudinal axis, which is not measureable using these positions, is an important part of PNF exercises.

In this research, with emphasis on all the details of a correct PNF exercise, including rotation of forearm, we combine real-time marker detection with the depth sensing capability of Kinects and its ability to recognize human posture to develop a prototype software that can evaluate the user's ability in performing PNF patterns of the upper limbs, while providing the patient with real-time visual feedback in a virtual reality environment.

M. Owlia and M. Khabbazan are with the Research Center for Biomedical Technologies and Robotics (RCBTR), Tehran University of Medical Sciences, Tehran, Iran and with the School of Mechanical Engineering, University of Tehran, Tehran, Iran (e-mail: mohammad.owlia@ut.ac.ir, m.khabbazan@ut.ac.ir).

M. H. Azarsa is with the Department of Medical Physics and Biomedical Engineering, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran (e-mail: mh-azarsa@razi.tums.ac.ir).

A. Mirbagheri is with the RCBTR, Tehran University of Medical Sciences, Tehran, Iran and with the Department of Medical Physics and Biomedical Engineering, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran (phone: +98-21-66581530, fax: +98-21-66581533, e-mail: a-mirbagheri@tums.ac.ir).

II. Procedure and Method

A. Software

In order to assess the user's movement, a Microsoft Kinect (v1.0) sensor was used. As PNF exercises require the patient to rotate their arm around its main axis, the *skeleton* that is detectable using Microsoft Kinect SDK is not enough for measuring such movements. So it was necessary to implement an image processing technique that is robust, as the accuracy of software's performance evaluation system is highly dependent on marker detection quality. Also, Speed of image processing is vital, as it is essential to detect the position of the marker, and subsequently rotation of the forearm, with a rate of 30 frames per second, the same as Kinect's skeleton data. For this purpose, in each frame, first the region of interest is restricted to an area around the *hand* joint, detected by Kinect's SDK. Then using a process similar to [11], the color marker is detected in this ROI. This algorithm estimates center of marker using edge detection and subsequently, finding the center of the circle that passes through most random picks of three boundary pixels. Also a spherical color marker was attached to the user's hand with a rod. Therefore, hand and Marker will have a constant distance from each other. Then using real time image processing (Fig. 1), the color marker was detected in 2D color image of Kinect RGB camera. By mapping the aforementioned image on the depth stream, generated using structured infrared laser light, the distance of the marker from the sensor was estimated. This, along with the position of the center of the color marker in the 2D image, allows one to identify the position of the color marker in 3D coordination of the real world and relative to the joints' positions that are included in Kinect's skeleton stream. The offset between the marker and main axis of the patient's forearm allows detection of the arm's rotation along this axis using geometric relations. Another important issue in this interactive system is the visual feedback that is crucial in providing the patient with an appropriate learning, consistent training and subsequently, increased motivation in exercise therapy. For this purpose, the software instantly provides a virtual reality (VR) environment with the position of the user's joints and color marker. A 3D avatar of the user is constructed accordingly, with the guidance of reference virtual paths for hand-wrist and color marker that are dynamically generated in front of the user's representation in the VR environment (Fig. 2). This reference virtual path should be pre-recorded for each patient under the supervision and with corrections from an expert physician. The patient can then repeat the exercise several times while receiving appropriate visual feedback. The Visual feedback in this system is recoloring/blinking and warning of the reference path of each hand-wrist and/or marker (blue and red path, respectively in Fig. 2) when the user deviates from them. The recorded data can be used to create a reference that is suitable for facilitating patients' rehabilitation.

B. Experiments

The Kinect Sensor was placed at the height of about 120 centimeters and in front of an expert physiotherapist. While recording the joints and marker positions, the patient repeatedly performed the correct movement patterns of PNF in upper limb. For example, the first pattern in the upper limb (D1 Flx) includes: finger flexion, wrist flexion and radial deviation, forearm supination, shoulder adduction and elbow flexion, shoulder flexion, elevation and external rotation. The second pattern of upper limb includes: finger extension, wrist extension and ulnar deviation, forearm supination, shoulder abduction and elbow extension, shoulder flexion, elevation and external rotation (D2 Flx). It should be noted that the movements were performed diagonally, starting from the distal joints, before ending the full range of motion in the distal joints, the movements begins in the proximal joints.

III. Results

The data that were recorded from the movement patterns of an expert physiotherapist are included in Fig. 3. All of the positions in this figure are relative to the *Spine* joint, detected by Kinect's SDK, and in millimeters. In order to the convert X and Y positions of the marker in the image that is in pixels to real world units, the geometrical relations proposed by [12] was used. Z is the distance of point from Kinect, originated from depth stream, and is in millimeters.

The results show that there is a proper compatibility between movements of hand, wrist and rotational marker in both D1 and D2 patterns of upper limb. The results of the rotational color marker were considered as an index for the movements of the total limb. These findings and their changing on the movement path was congruent with the movement principles of the limb in its specific pattern in all three dimensions.

X and Y axes data are related to the horizontal and vertical displacement of the marker in the plane that is a perpendicular plane, and by moving from right to left of the human body and from top to bottom, the amount of X and Y decreased and reached negative values.

In recorded movement patterns, the convex of motion curves are related to Z-axis (the depth of images). In the beginning of the movement at D1-Flx, the hand and rotational marker are in the *over stretched* position (internal rotation, extension and abduction), and by moving to the *flexion* position (flexion, external rotation and adduction), the depth of image decreases (Fig. 3, Flx). In D2-Ext, the X and Y values of the color marker position decrease, but the Z component of the movement indicates going to further depths. In D2-Flx, the X component is incremental while Z is decreasing in the beginning, but soon after, the depth of all three points begins to increase (Fig. 3, Ext and Flx).

IV. Discussion

The purpose of the current study was to design an *interactive system* using Kinect camera for evaluating and training the movement patterns of the upper limb based on PNF principles. In this study, by designing a virtual environment, the subject could move his/her upper limbs in specified patterns and in particular directions.

One of the most important aspects of PNF patterns is the total limb rotation and its consistency during the movement's path. This was obtained using a detectable color marker that is attached to user's hand with a rod. This allows the program to estimate such a rotation based on the position of the marker and the hand.

Our findings showed that the Kinect sensor is capable of robustly detecting the position of three indicators of PNF exercises: hand, wrist and rotational color marker with respect to a reference, which in this case is the *spine* joint (as detected by Kinect's SDK). This demonstrates that Kinect coupled with a color marker, can serve as a good method for detecting the movement patterns of PNF.

Even though the positions predicted by this method for each joint, as well as the color marker, might not be as accurate as other position sensing technologies, the results of this study indicate that this system is capable of providing a detecting movement and rotation patterns with an acceptable precision.

Using the VR environment, the software can quantify the patient's performance simultaneously by calculating the deviation between the positions of hand, wrist and marker from the above mentioned standard paths, and store them for further investigation by the physiotherapist. Also using this interactive method with real-time visual feedback may encourage patients to correct themselves at home based on the rehabilitation methods.

The main procedure that the author deems should be done more accurately is to study the effect of using this system during a case-control method.

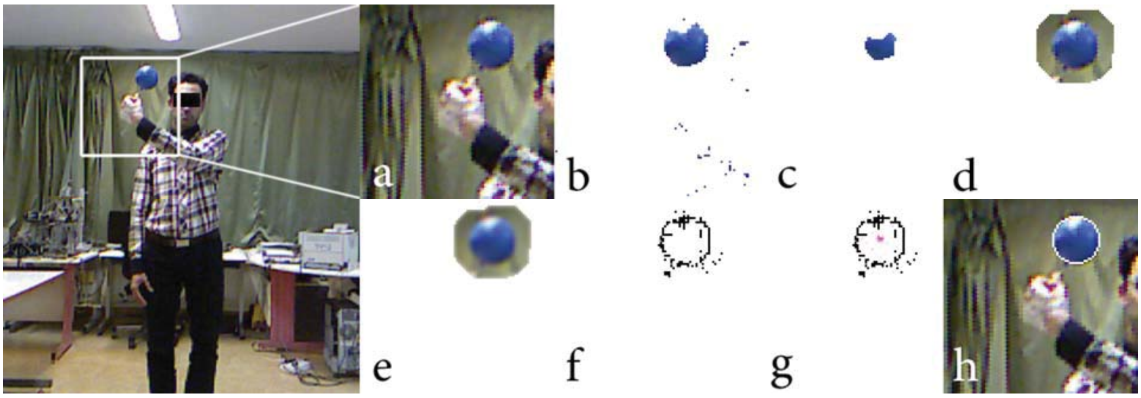

Fig. 1 Marker detection procedure: (a) selecting area around "hand" detected by Kinect SDK, (b) applying depth and hue thresholds, (c) erosion of selected pixels, (d) dilation, (e) applying Gaussian blur filter, (f) edge detection, (g) histogram of probable circles' center, (h) estimated circle

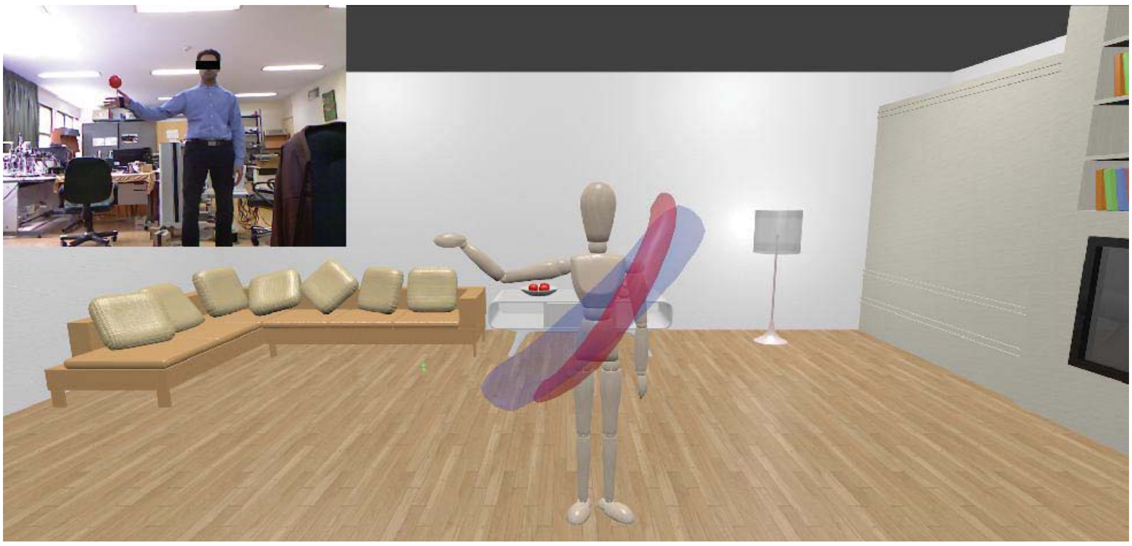

Fig. 2 VR Environment used for providing the patient with appropriate visual feedback and training. The blue path is for wrist and hand, while the red path is for marker

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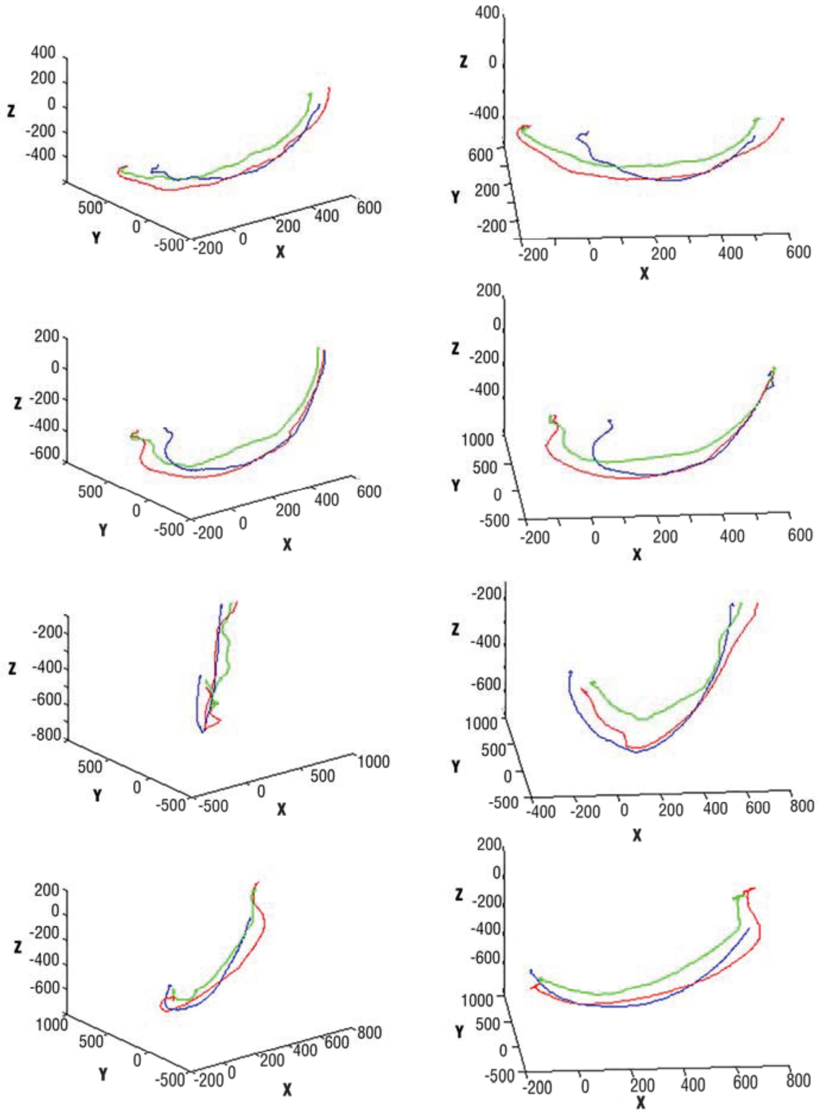

Fig. 3 Sample recorded data of an expert physiotherapist performing PNF exercises of Upper Extremities. Marker is shown with blue, hand with red and wrist with green (units are in mm)

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