



The feasibility of using the Microsoft Kinect™ to measure the degree of movements' precision for affected upper limbs motion of children with hemiplegia in home-based therapy: Feasibility study

Mohammed Elsaeh

Faculty of Information Technology, University of Sebha, Sebha, Libya

Corresponding author: moha.elsaeh@sebhau.edu.ly

Abstract Home-based therapy, that base on haptic-virtual games systems, increases the overall time of the therapy for hemiplegic children. Low cost depth sensors might be needed to evaluate the joint coordinates in order to produce movements. In this study, a body modulation and clinically-based angle calculations for random upper limb movements in 3D space have been created and validated. The shoulder joint flexion-extension angle, shoulder abduction-adduction angle, elbow flexion-extension, wrist flexion-extension angle and wrist abduction-adduction angle has been performed by a subject. Kinect™ system and the Vicon motion capture system have been used to measure those movements. Results illustrate a clinically acceptable error of these movements and its angles which around 4.9% for shoulder joint, around 3.9% for elbow joint, and around 4.8% for wrist joint for most cases.

Keywords: Hemiplegia; kinect; virtual; home-therapy; evaluation; upper limb; joints coordination.

جدوى استخدام حساسات الكينيكيت لقياس درجة دقة الحركات للأطراف العلوية المتأثرة للأطفال المصابين

بشمل نصفي اثناء العلاج المنزلي: دراسة جدوى

محمد السايح

كلية تقنية المعلومات-جامعة سبها، ليبيا

للمراسلة: moha.elsaeh@sebhau.edu.ly

الملخص العلاج في المنزل، الذي يقوم على أنظمة الألعاب الافتراضية والروبوتات، يزيد من الوقت الإجمالي للعلاج للأطفال المصابين بشمل نصفي. قد تكون هناك حاجة إلى أجهزة استشعار العمق منخفضة التكلفة لتقييم تناغم المفاصل المشاركه في إنتاج الحركات المختلفة للأطراف العلوية. في هذه الدراسة، تم إنشاء والتحقق من صحة نمذجة الجسم المقترحة وحساب الزوايا المتكونة عند كل مفصل والمستندة إلى التعريفات الطبية لحركات الطرف العلوي العشوائي في الفضاء ثلاثي الأبعاد. تم حساب زوايا تمديد وانتداء مفصل الكتف وزاوية اختطاف الكتف وتمديد وانحناء المرفق وزاوية تمديد وانحناء المعصم وزاوية اختطاف المعصم والتي تم تنفيذها بواسطة المتطوع. تم استخدام نظام الكينيكيت ونظام التقاط الحركة فيكون لقياس تلك الحركات. توضح النتائج وجود خطأ مقبول إكلينيكياً لهذه الحركات وزواياها والتي تبلغ حوالي 4.9% لمفصل الكتف وحوالي 3.9% لمفصل الكوع وحوالي 4.8% لمفصل الرسغ لمعظم الحالات.

الكلمات المفتاحية: شمل نصفي، كينيكيت، الواقع الافتراضي، العلاج المنزلي، التقييم، الطرف العلوي، تنسيق المفاصل.

I. INTRODUCTION

Hemiplegia is a part of Cerebral Palsy (CP) in which one side of the body is paralyzed as a result of brain damage [1]. As consequences of this illness, many abilities weaknesses including upper limbs have been noticed [2, 3]. Considerable improvements of Upper Limbs (UL) functions have been pointed from different rehabilitation therapy [4].

Robotics therapy can be defined as that training patient to improve their abilities which have been affected, like stroke and CP [5]. Robotics can be used in the therapy field as assistive or resistive therapy. Haptic devices have been used as a resistive therapy in order to facilitate repetitive movements training for individuals [6, 7]. Those haptics can be integrated with virtual environments to provide its tactile feedback according to virtual reality VR scenes. By using a portable haptic device, rather than high costly and heavy robots, with virtual environment, we can

provide children with hemiplegia with motivated home-based therapy.

VR provides visual and audio feedback to the patients; also it provides a useful data, about the activities that have been done by the patients, to the therapists [8, 9, and 10]. By using VR, patients can instantly see visual and audio feedback. Meanwhile, tactile feedback is provided by the haptic device, which will help them to recover functions of their upper limbs. But therapists need to know the data about the movement of the upper limb during performing tasks at home such as shoulder flexion-extension, shoulder abduction-adduction, shoulder rotation, elbow flexion-extension and so on.

Inexpensive assessment device the Microsoft kinect™ might be used in order to translate this information to the therapists. Kinect™ is a promising solution for home-based assessment because of its portability, work-space and price. In fact, this motion assessment device (kinect™) has

been used in home-care: 1) To track the motion performance [11]. 2) In fall risk assessment at homes [12]. 3) To record posture and movements in 3D space to determine the risk of musculoskeletal injury in the workplace [13]. In these experiments, kinect™ has been used mainly to provide the position of the body joints in 3D according to the position of the kinect, and give the trajectories which have been made by each joint. Whereas the type of the movements along with thetas that have been made in each movement are needed by the therapist to observe the use of joint coordinate system by the hemiplegic children. For example, has the child make shoulder flexion-extension to perform certain movement that required flexion-extension? Or, has he performed other compensations like shoulder abduction-adduction to perform that movement?

There is a study which has used the kinect™ to determine the type of shoulder movements and the created thetas during those movements [14]. They have used the circle which was created by the movement of the arm to determine the type of the shoulder movement (flexion-extension, and abduction-adduction) and the related theta. In this study, we have used the collected joints' data from the kinect™ to determine the type of the movements of all upper limbs segments and the related thetas to be given to the therapists of children with hemiplegia to enable them to judge the joint coordination system during movements for those children in home-based therapy.

II. PROPOSED SYSTEM

The purpose of this proposed system is to accurately determine the type of the upper limb movements and the exact thetas that were created during those movements in 3D space. We based on the classification of the upper limb joints defined by Theresa Bissell and Laura Steele [15] to build our new upper limb module which will allow us to determine those different types of upper limb movements in 3D space as can be seen in Fig.1.

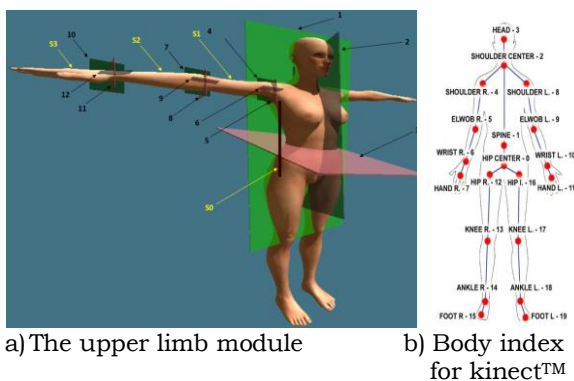


Figure 1: The upper limb description

As can be seen from Fig.1 there are the three main body planes coronal, sagittal and transverse which markers in the figure as 1, 2, and 3 respectively. And for each upper limb joint we create the related three planes based on the fixed index to that joint. For example, the fixed index for the shoulder joint planes is the center shoulder-right shoulder vector, the fixed index for the elbow joint planes is the right shoulder-right elbow vector, and the fixed index for

the wrist joint planes is the right elbow-right wrist vector. And in the same order for the left upper limb.

Theresa Bissell and Laura Steele [15] have classified the shoulder joint under the synovial joint classification, in which the Angular movements increase or decrease the angle between two bones. Then, flexion movement decreases the angle of the joint and brings the articulating bones closer together see Fig. 2.a; extension movement increases the angle between the articulating bones see Fig. 2.b; abduction is the movement of a limb away from the midline body see Fig. 2.c; and adduction is the movement of a limb toward the midline of the body see Fig. 2.d. But they have also classified the pivot joints as a type of the synovial joint, these pivot joints consist of a rounded structure that protrudes into a sleeve or ring, and allow uniaxial rotation of a bone around the long axis, which gives the shoulder the possibility to move from the flexion movement to the abduction movement in the same or different thetas. From this definition, we need to define the exact shoulder flexion-extension movements, the exact abduction-adduction movements and most common in-between flexion-abduction movements in 3D space.

We redefine the flexion extension movements in 3D space as the intersection of the transverse plane -6- of the shoulder with the sagittal plane of the body -2-. If there is no intersection then we are in the exact flexion-extension movement. In order to facilitate the intersection determination between these two planes, we calculate the normal vector of each of those two planes, to determine whether they are: a) parallel (no intersection) as in (1), b) perpendicular which means the movement is the exact abduction-adduction movement as in (2), theta of these two movements can be calculated from the created angle between the right shoulder-right elbow vector (S1) and the shafted center shoulder-neck vector (S0) as in (3), c) or they are not parallel and not perpendicular. So, we are in-between flexion-abduction movement and we need to calculate the angle of rotation in the Y axis of the shoulder to find the degree of affiliation of that movement to flexion or abduction movement. In this case we calculate the angle between the planes -4- and -3- as in (4).

$$\frac{x}{a} = \frac{y}{b} = \frac{z}{c}. \text{ Whereas } V_1 = \langle x, y, z \rangle,$$

$$V_2 = \langle a, b, c \rangle \tag{1}$$

$$V_1 * V_2 = (x) * (a) + (y) * (b) + (z) * (c) = 0 \tag{2}$$

$$\cos(\theta) = \frac{((x) * (a) + (y) * (b) + (z) * (c))}{\sqrt{x^2 + y^2 + z^2} * \sqrt{a^2 + b^2 + c^2}} \tag{3}$$

Where V_1 represents the normal vector of plane -6-, and V_2 represents the normal vector of plane -2-

$$\cos(\theta) = \frac{((x) * (a) + (y) * (b) + (z) * (c))}{\sqrt{x^2 + y^2 + z^2} * \sqrt{a^2 + b^2 + c^2}} \tag{4}$$

Where V_1 represent the normal vector of plane -4-, and V_2 represent the normal vector of plane -3-

For the elbow joint, they [15] have related the flexion-extension movements to the hinge joint which makes a smooth stable movement. In our system, the elbow angle is calculated in 3D from the angle between the two vectors (S1, S2) as in (3) where V_1 and V_2 represent S1 and S2 respectively. Knowing that the projection of the vector -S2- is always on the plane -9-

For the wrist joint, the wrist flexion-extension angle is created by the projection of the vector -S3- onto the plane -10- which has the normal vector D1, the vector D1 is created by the null product of the vector -S2- as in (5). The wrist abduction-adduction angle is created by the projection of the vector -S3- onto the plane -12- which has the normal vector D2, the vector D2 is created by the null product of the vector -S2- as in (6).

$$D = \text{null}(S2), \text{ and then } D1 = D (:1) \quad (5)$$

$$D = \text{null}(S2), \text{ and then } D2 = D (:2) \quad (6)$$

The projection of the vector -S3- onto plane D1 and D2 is called P1 and P2 respectively. The flexion extension angle and the abduction adduction angle can be found by calculating the angle between the vector -S2- and P1 in the flexion-extension, and the angle between the vector -S2- and P2 in the abduction-adduction as in (3).

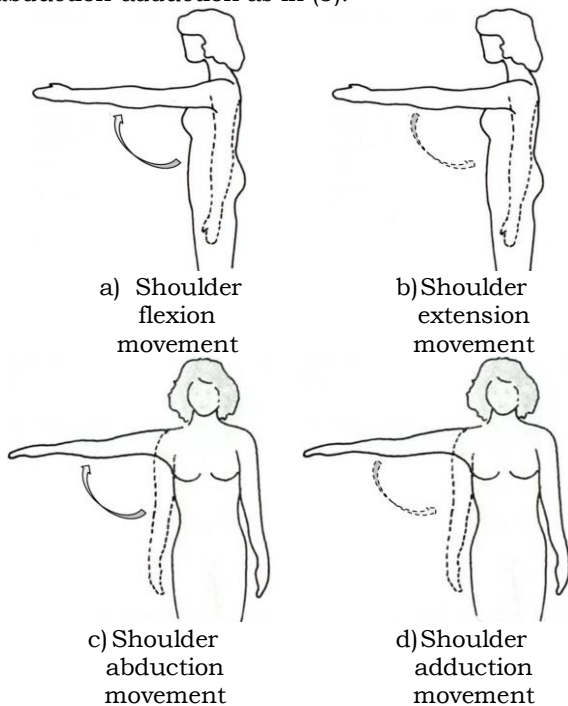


Figure 2: the shoulder different movements

III. EQUIPMENTS

A. Kinect

The Kinect consists of three sensors: a projector (an infrared IR emitter), a camera (a RGB color sensor) and an IR camera (an IR depth sensor) as in Fig. 3. Body tracking is performed using the depth sensor, so the coordinates (X, Y and Z) of the body joints are correctly aligned with the depth frame only. The Kinect for Windows version 2 SDK 2:0 determines skeleton position information from the provided depth image. The result is Cartesian

coordinates of joint positions related in meters with the Kinect depth sensor center as the origin. These skeletons acquire at a rate of about 20 to 26 samples per second [16].

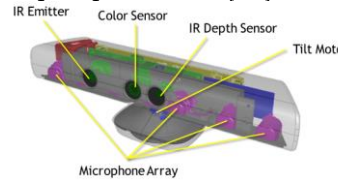


Figure 3: Kinect™ for windows



Figure 4: Vicon system

B. Vicon

The 3D motion capture system of the Valenciennes Movement Analysis Laboratory is a VICON® system (Vicon Motion Systems Ltd., Oxford, UK) with 8 MX T20 cameras, with a sampling frequency of 100 Hz Fig. 4.

IV. CASE STUDY

Procedure

In order to use kinect™ to find out the type of the movement and to measure the related angles, we confirm its performance with the Vicon measure device. The subject, 28 years old, 172 cm, 75 kg, male has participated in 2018 at Polytechnic University of Hauts-de-France. He has performed most of movements which are needed in the upper limb therapy for children with hemiplegia. The subject was instructed to make shoulder flexion-extension, shoulder abduction-adduction, elbow flexion-extension, wrist flexion-extension and wrist abduction-adduction. Each type of movement has been repeated 3 times. These movements were measured by using both Vicon and kinect™ devices as in Fig. 5.

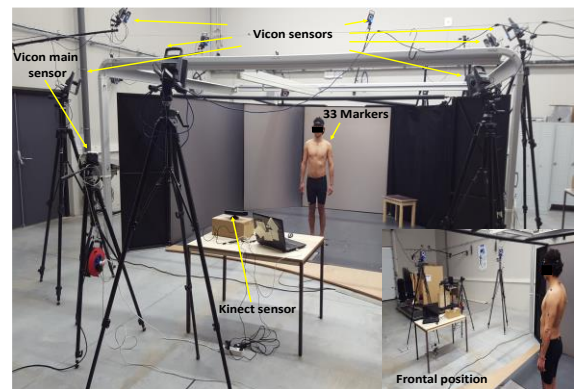
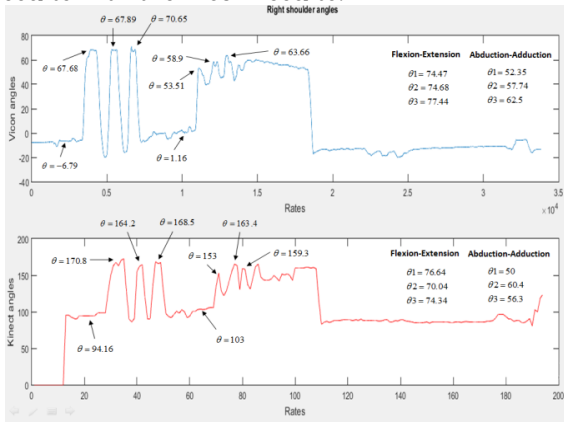


Figure 5: The Vicon and Kinect™ systems

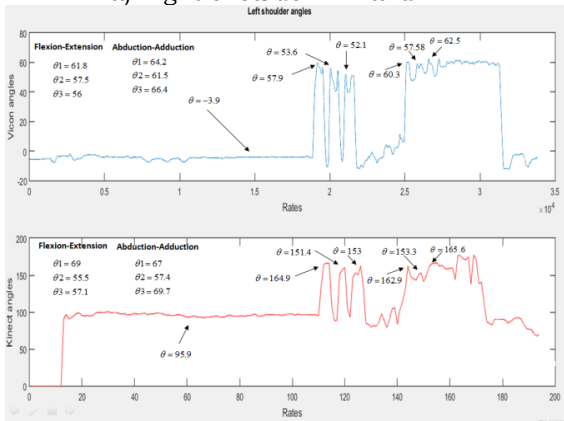
V. RESULTS AND DISCUSSION

Since the two data sets, the frame rates and time, between the Vicon and Kinect™ are widely different, to make a comparison we have based on the values that related to each type of movement and its angles for each peak point as can be seen in Fig. 6. In children with hemiplegia therapy processes, the therapists need to know whether or not children can perform a certain movement, for how much amplitude and can they do it separately or with other compensation movement. So, the assessment system should provide the therapists with all activities of all joints at all times along with the angles that have been performed by each joint.

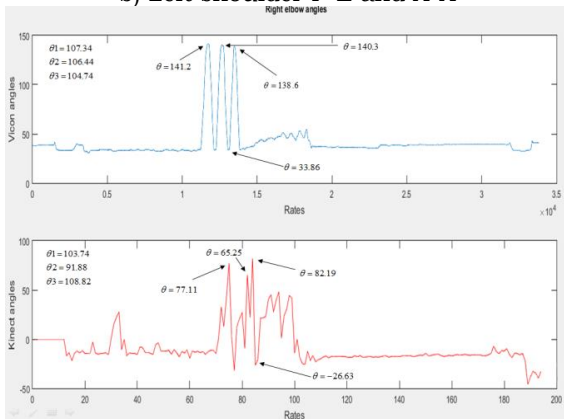
For example in shoulder joint Flexion-Extension movement, the therapists need to know that: Is the child able to perform shoulder Flexion-Extension? To which angle they can go? Is there any other compensation movement during performing this movement like elbow flexion? To that end, we have developed our assessment system and compare its results with the Vicon results.



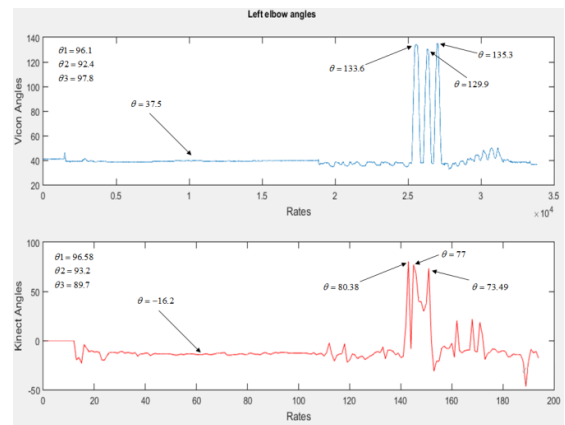
a) Right shoulder F-E and A-A



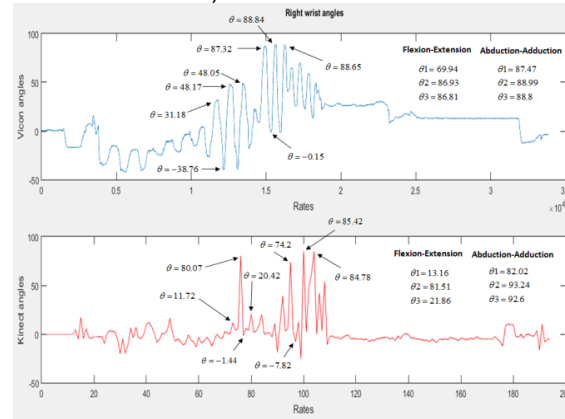
b) Left shoulder F-E and A-A



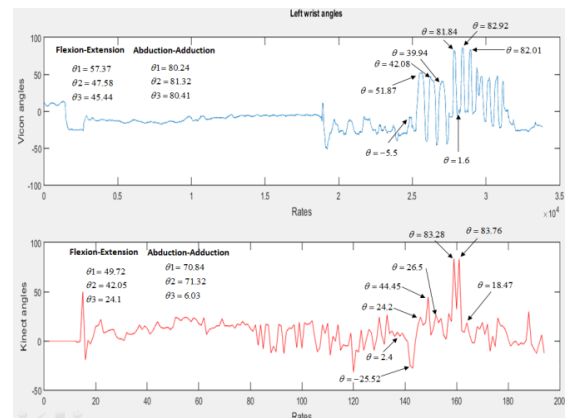
c) Right elbow F-E



d) Left elbow F-E



e) Right wrist F-E and A-A



f) Left wrist F-E and A-A

Figure 6: The right and left upper limb movements

Fig. 6 illustrates the activities that have been performed by each joint at all times. These activities have been measured at the same time by using the Kinect™ and the Vicon. Fig. 6.a. shows the right shoulder activities during the time, this joint has performed Flexion-Extension movements for three times and then it has performed Abduction-Adduction movements for three times. This joint stays almost steady for the rest of the time. Fig. 6.c. shows the right elbow activities during the time, this joint has performed Flexion-Extension movements for three times and then it remains steady for the rest of the time. Fig. 6.e. illustrates the right wrist activities during the time,

this joint has performed Flexion-Extension movements for three times, and then it has performed Abduction-Adduction movements for other three times and remains almost steady for the rest of the time. Fig. 6.b, d, and f. illustrate the activities that have been performed by the joints of the left upper limb during the time. From this comparison, it can be seen clearly that the kinect shows the type of the movement for all joints of the upper limb along with the other movements that might be performed at the same time.

Now, we need to answer the other question about the angles that have been performed by each joint at each movement type. To this end, we have calculated the errors (7) and its related percentage errors (8) for each peak point for each type of movement. Knowing that, each type of movement has been performed three times. We have defined error (E) and its related percentage (PE) as the ratio of the difference of the observed angles of both

Kinect™: ROM_K and Vicon: ROM_V

$$Error = MeasuredValue - ActualValue. \quad \text{So,}$$

$$E = ROM_K - ROM_V \quad (7)$$

$$PercentageError = \frac{|Error|}{ActualValue} * 100. \quad \text{So,}$$

$$PE = \frac{|E|}{ROM_V} * 100 \quad (8)$$

Table 1 illustrates the percentage error at all activities of each joint. We observe that the elbow Flexion-Extension movements for both right and left upper limb have the closest values and less percentage error comparing with the other joints percentage error 6.9 % and 3.1 % in average for right and left elbow Flexion-Extension respectively. Percentage errors of shoulder joint movements show promise results of using kinect™ to measure this joint. Percentage errors of wrist joint movements are less reliable. For example, for right wrist Abduction-Adduction movements the kinect™ has an important precision of about 5.03 % in average percentage error, but for the same joint in Flexion-Extension movements it has less precision for the first and third peaks and an acceptable percentage error in the second peak. For the left wrist, the results of the kinect™ can be used in most cases.

Table 1: the percentage errors of all upper limb joints during performing movements

			1 ^{ere} peak	2 ^{eme} peak	3 ^{eme} peak
Shoulder	Right	F-E	2.9 %	6.2 %	4.0 %
		A-A	4.4 %	4.6 %	9.9 %
	Left	F-E	11.6 %	3.4 %	1.9 %
		A-A	4.3 %	6.6 %	4.9 %
Elbow	Right	F-E	3.3 %	13.6 %	3.8 %
	Left	F-E	0.4 %	0.8 %	8.2 %
Wrist	Right	F-E	81.1 %	6.2 %	74.8 %
		A-A	6.2 %	4.7 %	4.2 %
	Left	F-E	13.3 %	11.6 %	46.9 %
		A-A	11.7 %	12.2 %	92.5 %

In this paper, arm motions have been classified by the researchers, measured by using Kinect™ device

and validated by comparing the results of the Kinect™ with the Vicon results. Although the frame rate of the Kinect™ (194 angles in the all period of time) is largely smaller than the frame rate of the Vicon (33847 angles in the same period of time), the Kinect™ was able to provide the type of the movement for each joint at each specified time, the history of each joint movements and the combined movements at each time point, and the angles performed by each joint with an acceptable error in most cases.

Nowadays, according to our knowledge, there is a lack of markerless methods for quantitative assessment especially in Home-based therapy. In this work, we have presented results which help the therapists to judge the therapy process for children with hemiplegia based on the presented objective assessment method. These results can be gained by using inexpensive assessment device, markerless and easy to install which is the best choice for therapy at home.

VI. CONCLUSIONS & FUTURE WORK

Most motions, which related to all upper limb joints, have been performed such as shoulder Flexion-Extension, shoulder Abduction-Adduction, Elbow Flexion-Extension, Wrist Flexion-Extension and Wrist Abduction-Adduction. We have developed a quantitative assessment method using Microsoft Kinect™ and based on the existing clinical definition of the upper limb motion. Finally a comparison between the results of our system and the results of the Vicon system has been done. This comparison shows a potential use of the Kinect™ in Home-based therapy for children with hemiplegia.

We recognize that the medical specialists would prefer a conclusion of the joint motion along with the results of those motions. So, the future work will concentrate on developing an algorithm that will be based on the numeric data, which will be collected by the Kinect™, to systematically provide therapists with a summary of the joints motions. An exploration of the effects of filtering methods on the kinect's results needs to be done in the future work.

References:

- [1]- Radomski, Mary Vining, and Catherine A. Trombly Latham, eds. Occupational therapy for physical dysfunction. Lippincott Williams & Wilkins, 2008.
- [2]- C. A. Giuliani, Dorsal rhizotomy for children with cerebral palsy: support for concepts of motor control, J Phys Ther 71 (1991) 248/59.
- [3]- Nicholson, J. H., et al. "Assessment of upper-limb function and movement in children with cerebral palsy wearing lycra garments." Developmental Medicine and Child Neurology 43.6 (2001): 384-391.
- [4]- Song, Chiang-Soon. "Effects of task-oriented approach on affected arm function in children with spastic hemiplegia due to cerebral palsy." Journal of physical therapy science 26.6 (2014): 797-800.
- [5]- Winter, David A. "Human balance and posture control during standing and walking." Gait & posture 3.4 (1995): 193-214.

- [6]- Van der Linde, R. Q., and P. Lammertse. "HapticMaster-a generic force controlled robot for human interaction." *Industrial Robot: An International Journal* 30.6 (2003): 515-524.
- [7]- Adamovich, Sergei V., et al. "Incorporating haptic effects into three-dimensional virtual environments to train the hemiparetic upper extremity." *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 17.5 (2009): 512-520.
- [8]- M. J. D. Taylor, D. McCormick, T. Shawis, R. Impson, and M. Griffin, "Activity-promoting gaming systems in exercise and rehabilitation," *The Journal of Rehabilitation Research and Development*, vol. 48, no. 10, p. 1171, 2011.
- [9]- A. De Mauro, "Virtual Reality Based Rehabilitation and Game Technology," *EICS4Med 2011*, vol. i, pp. 48-52, 2011.
- [10]- K. Jordan and M. Sampson, "ImAble system for upper limb stroke rehabilitation," in *International Conference on Virtual Rehabilitation*, 2011, pp. 1-2.
- [11]- C.-Y. Chang, B. Lange, M. Zhang, S. Koenig, P. Requejo, N. Somboon, A. Sawchuk, and A. Rizzo, "Towards Pervasive Physical Rehabilitation Using Microsoft Kinect," *Proceedings of the 6th International Conference on Pervasive Computing Technologies for Healthcare*, pp. 2-5, 2012.
- [12]- E. Stone and M. Skubic, "Evaluation of an Inexpensive Depth Camera for Passive In-Home Fall Risk Assessment," *Proceedings of the 5th International ICST Conference on Pervasive Computing Technologies for Healthcare*, 2011.
- [13]- T. Dutta, "Evaluation of the Kinect™ sensor for 3-D kinematic measurement in the workplace.," *Applied ergonomics*, vol. 43, no. 4, pp. 645-9, Jul. 2012
- [14]- Nixon, Mason E., Ayanna M. Howard, and Yu-Ping Chen. "Quantitative evaluation of the Microsoft Kinect™ for use in an upper extremity virtual rehabilitation environment." *Virtual Rehabilitation (ICVR), 2013 International Conference on. IEEE*, 2013.
- [15]- Marieb, Elaine Nicpon, and Katja Hoehn. *Human anatomy & physiology*. Pearson Education, 2007.
- [16]- Jana, Abhijit. *Kinect for windows SDK programming guide*. Packt Publishing Ltd, 2012.