MARKERLESS GESTURE RECOGNITION ACCORDING TO BIOMECHANICAL CONVENTION

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Abstract: During rehabilitation it is important to perform determined exercises according to joint biomechanics in order to achieve the right improvements. In order to rehabilitation systems and applications to be able of recognizing movements according to these necessities, this paper proposes a gesture recognition method developed considering International Society of Biomechanics standards for upper and lower limbs. Joints positions were obtained through Kinect sensor and the angles between consecutive joints associated with normal vectors of the anatomic planes were computed based on body references. Movements of upper and lower limbs were classified according to the biomechanical standards. All movements were tested by a specialized physiotherapist. Each movement was performed 60 times: 20 correct executions at normal velocity, 20 fast and 20 wrong performances. These movements were submitted to different movement tolerance margins in order to analyze the most adequate for applications. The method proposed presented good capability in classifying biomechanical exercises, and therefore, it is indicated as recognition method for rehabilitation applications.

Keywords: Gesture Recognition, Biomechanics, Rehabilitation, Kinect.

Introduction

Computational systems developed to aid rehabilitation process have the intention to optimize and motivate it. Due the technological advances the number of such systems has been growing in research and clinical applications. One example is KiReS, a rehabilitation system created to motivate and guide the exercise. This system uses a sensor to detect the body's position and the patient can interact with a game through a pre-recorded therapeutic exercise. An evaluation about patient performance is given after the game [1].

In order to achieve goals during rehabilitation process it is important to consider movements according to joint anatomy and biomechanics [2]. Until now there is a lot of interactive rehabilitation systems developed to help rehabilitation process, however the gesture and movement recognition performed by them are commonly related to reaching movements or movement reproduction [1], or balancing exercises [3].

For general and complementary rehabilitation processes these exercises tend to be enough. However at some therapy stages, the clinical environment is not required anymore but exercises are yet indicated to maintain improvements. There are also the cases where patients cannot have access to clinics due economical or geographic limitation. In these cases it is important for the system to be able to guide the user through the treatment without therapist supervision. So, this paper proposes a gesture recognition method for upper and lower limbs developed taking in consideration the International Society of Biomechanical (ISB) standards [4] to be used on interactive or evaluative systems in a more clinical practice compatibility way.

Materials and methods

Intending to perform gesture recognition based on a biomechanical standard [4, 5] this research will make use of the Microsoft Kinect [6]. This sensor was chosen due its markerless body tracking and also due its cost and practicality, allowing easy use not only in clinical environments but also at home. After choosing the sensor it was necessary to define characteristics and requirements of biomechanical movements.

Biomechanical movements are described based on the planes where the limb (bone) moves at each joint. In order to analyze such movements the origin of Cartesian system is centralized at each joint (Figure 1), and the movement of the vector, representing the bone, is then evaluated.

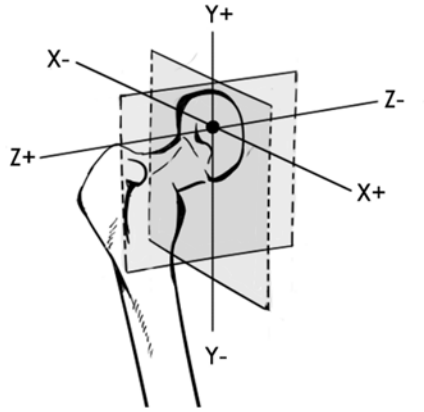

Figure 1. Cartesian system centered at right hip joint.

The ISB standardizes the axes as follows: Y axis parallel to gravity pointing upward; X axis directed anteriorly; and Z axis for the right [4]. Each pair of axes composes a plane which receives a specific name in biomechanics: Sagittal (XY); Frontal (YZ) and Horizontal (XZ) planes. The anatomic position, standing up with hand's palm facing forward and toes pointed to the front, is another reference required for movement description which is associated to the initial human body position [7]. Based on these references it is then possible to classify the movements and compute their Range of Motion (ROM) at each plane. [7].

Gesture Recognition based on biomechanical parameters – Following these movements' descriptors references a gesture recognition technique was developed. The first step was to obtain joints positions from the sensor and use them in a more appropriate body representation.

The Kinect sensor gives three-dimensional joint positions containing X, Y and Z coordinates centered on camera view in real time. Based on these positions, body segments could be represented by vectors connecting two successive joints, e.g. forearm segment can be represented by a vector from the wrist to the elbow and the thigh by a knee to hip vector. With segments established, it is now possible to compute the angle between two successive segments. For example, the knee angle computation is presented in Equation 1.

$$\text{kneeAngle} = \arccos\left(\frac{\text{leg} \cdot \text{thigh}}{\|\text{leg}\| \, \|\text{thigh}\|}\right) \qquad (1)$$

However, it is important to notice that the angle measured by this formula is independent of the plane in which the bone is moving. But, for movement classification and properly ROM measure, the movement must be performed in a specific plane. The direct angle measure with no specification of the plane where it is being performed results in ambiguity. For example, thigh positioned at 60 degrees, it can be frontally (at Sagittal plane) or laterally. Anatomically these movements are different, Flexion and Abduction respectively. The system capability to differentiate them is important since they produce different results on rehabilitation gains [2].

To solve these problems in the angle analysis an additional measure was performed to define and guarantee that the movement is being executed within a determinate plane during interaction or evaluation. In order to do that the normal vector of each plane was computed. With this information the angle between the segments that is moving and the normal could be computed and used further to describe movements.

As presented before, to describe a biomechanical movement it is necessary to center the Cartesian system at the joint center. In this method the Cartesian system will be composed by the normal vectors of three planes. For the joints attached to the trunk, the normal vectors will be computed as follows. Normal of Horizontal plane (Y axis): spine center to neck vector; Normal of Frontal plane (X axis): cross product between a vector that goes from one shoulder to another and Y axis; Normal of Sagittal plane (Z axis): cross product between the others two normal vectors.

For the distal joints, such as elbow and knee, it is not possible to use the trunk normal vector so a specific normal computation is required. This occurs due the fact that they are not attached directly to the trunk, so they are dependent of limbs position and change according to them. For distal joints, normal will be computed based on the surrounding bones and the cross product between them, as follows. Normal of Horizontal plane (Y axis): composed by the longitudinal axis of the proximal bone of joint, e.g. for the elbow thy Y axis is composed by the arm and for the ankle the axis is represented by the leg (tibia and fibula). Normal of Sagittal plane (Z axis): computed by the cross product of the two big bones of limb. This means arm and forearm for upper limb distal joints, and thigh and leg for lower limbs. Normal of Frontal plane (X axis): achieved by the cross product between Y and Z axes.

The centralization of the Cartesian system at each joint enables recognition of biomechanical movements according to the ISB standard. Besides it also provides the system with the important characteristic of enable angle measurement independently of user orientation in relation to sensor, since it changes the three-dimensional reference from camera view to user body.

With the specific basis computed for each extracted joint it is now possible to classify the biomechanical movements. For a movement to be classified in a determined plane the angle between the moving vector and the normal vector of its plane for the specific joint should be 90 degrees. However, since the complete perfect movement at 90 degrees would be utopic for body movement the Movement Tolerance Margin was implemented (MTM), which can be specified by the user. Through this configurable MTM it is possible to define how far away from the plane the movement will be acceptable to be classified as a biomechanical movement from that determined plane. This study recognizes and classifies upper and lower limbs movements, listed in Table 1 at Results section.

Tests – After development, tests were performed in order to evaluate the system in terms of performance and recognition capacity. The tests were performed on an Intel I7 with 8GB of RAM notebook. A Kinect sensor was connected to this computer and user must be stand in front of the sensor.

In order to evaluate the recognition, movements were performed in a correct and wrong way and the success rate of recognition by the system was scored. In order to guarantee that the movements were performed in a correct way the movements were performed by one physiotherapist specialized on biomechanics and with gymnastic preparation due to the fact that its practice and corporal conscience favors the performance of more precise movements. The person who performed the movements was carefully chosen and guided to perform them as perfect as possible since they would be interpreted as correct.

Each classified movement (Table 1) was performed 60 times: 40 times correct (20 at normal and 20 at fast velocity) and 20 times wrong (out of its respective plane). The tests were recorded using Kinect Studio enabled by the SDK [6] and this way the tests could be performed at different MTM with exactly the same input to avoid bias. The tests with the different MTM were performed trying to find the more adequate value for it in each biomechanical movement, where tracking and recognition have lower fail rate. During all movement performance the system was evaluating its execution in real time. To evaluate the data and compute success rate, graphics with the angles during movement were plotted and value of -20 was assigned when the movement was out of plane. When at any part of the movement this value was found the movement was computed as a wrong exercise. Movements performed at the Frontal plane were made with user facing the sensor and for the Sagittal plane user positioned rotated around 30 degrees to not occlude joints during movement.

Data analysis: In order to analyze the data obtained from tests the success rates were computed. A descriptive analysis with percentage for each movement at different MTM was performed to present data. Since there was no different groups none comparative test were required.

Results and Discussion

This paper presents a gesture recognition method aiming that movements can be recognized according to biomechanical standards. This method can be then used in an interactive and evaluative system enabling to have a clinical language being more friendly and effective for therapy.

The gesture recognition here proposed presented good capability to classify biomechanical movements for the main limbs joints. The method was also able to detect when the movement is being performed in a wrong way. This last feature is very useful for rehabilitation interactive systems which can make use of it to correct and guide patient during exercise [8].

Table 1 presents all movements classified and the tests results. The success rate of recognition for each movement at different MTM is presented.

With the results presented in Table 1 it is possible to notice that the use of 10º MTM makes the recognition unstable. This occurs because although the movements are described in planes, the performance of them exactly at the plane during all trajectories is utopic. For shoulder movements at this MTM Horizontal Abduction could be recognized successfully (95 and 100%). However the shoulder Flexion performed quickly has a low success rate (55%). The other shoulder movements presented success rate from 70% to more. Depending of the aim of the application, in case of high precision of movement required this range can be used. For hip movements all movements can use this range since it would not be performed at normal speed (success > 80%). For movements performed in a quick way this range success falls drastically achieving 20% for Abduction.

For elbow and knee only one pair of movements (Flexion and Extension) and one range test were performed and 100% success rate was achieved. This occurs due the fact that these joints do not perform movement at the Frontal plane (Abduction and Adduction) [2] which can be the deviation plane of Flexion and Extension and the movement is naturally performed perfectly at the Sagittal plane. The knee can also perform axial rotation at the Horizontal plane; however this movement is not detected by the Kinect skeleton recognition.

Table 1. Success rate of each classified biomechanical movement at different MTM.

Shoulder movements	**Speed**	**MTM 10º**	**20º**	**30º**
Abduction / Adduction	Normal	70%	100%	100%
	Fast	70%	100%	100%
	Wrong	100%	100%	100%
Flexion / Extension	Normal	70%	100%	100%
	Fast	55%	100%	100%
	Wrong	100%	100%	100%
Horizontal Abduction / Adduction	Normal	100%	100%	100%
	Fast	95%	100%	100%
	Wrong	100%	100%	35%
Elbow movements	**Speed**	**MTM 10º**		
Flexion / Extension	Normal	100%	-	-
	Fast	100%	-	-
Hip movements	**Speed**	**MTM 10º**	**20º**	**30º**
Abduction / Adduction	Normal	85%	100%	100%
	Fast	20%	100%	100%
	Wrong	100%	70%	15%
Flexion / Extension	Normal	80%	100%	100%
	Fast	45%	100%	100%
	Wrong	100%	100%	100%
Knee movements	**Speed**	**MTM 10º**	**15º**	**20º**
Flexion / Extension	Normal	100%	-	-
	Fast	100%	-	-

In an opposite way, the 30º MTM presented great success rate when detecting correct movements, since it gives more movement freedom. However it can in some case cause a false positive. When performing wrong exercises the system failed detecting them as correct at this range for shoulder Horizontal Adduction and Abduction and for hip Adduction and Abduction (35 and 15% respectively). However for all other movements tested this false positive case did not happen.

The ideal MTM is located at 20º MTM, presenting 100% success rate in detecting correct exercises. The only situation where this rate was not achieved was the false positives for hip Abduction and Adduction (70%). However for this movement the limitation reported by the therapist was the difficulty in performing this movement out of the plane more than 10 degrees due the joint anatomic congruency. So this movement is naturally performed correctly, being necessary just to differentiate it from the other joint movements.

It is important to notice that the success rate is related with the capacity of user to perform the movement in an accurate way. In case where the movement is very difficult to be performed as standardized the use of larger MTM in interactive systems is suggested in order to provide more usability.

The use of movement angles and its relation to the thorax normal vector enabled the user body analysis at different positions in relation to the sensor, including rotated and laterally displaced. This way, it is possible to provide the user a greater mobility during the use of the system, becoming one step closer to a natural interaction. Movements with different positions in relation to the sensor were also included in the correct performance test described before.

Distal joints, wrist and ankle, can also be recognized by the method. However, since the skeleton tracking provided by the current version of Kinect sensor presents a very unstable joint centralization for these joints they were not included in the tests. A new and more accurate version of the sensor is scheduled to be released yet this year.

Limitations are mainly related to the sensor and the markerless technique capability. One of the problems occurs when there is occlusion; there is an inaccuracy due to indirect estimation performed by the sensor when one body part covers the view of another. This may be improved with the use of multiple sensors. Another limitation is the detection of axial rotation. Since the system detects joint position based on pose estimation, the bone rotation around its own axis does not change the visual pose and no change on joint location is found. So, it is not possible to detect these movements by the method proposed. Future works to develop a method which can detect them based on additional references are ongoing.

Conclusion

The method here proposed for gesture recognition showed efficacy in classifying and recognizing movements according with biomechanical standards for both upper and lower limbs. All movements presented great success rate of movement recognition, mainly at 20º MTM. When accuracy is required in the application, attention should be given to the use of 30º MTM due the possibility of false positives. So, this method is indicated to be used in rehabilitation applications in order to enable these systems to be more related with clinical language and practice.

Future works include: evaluation of Kinect joints location stability; extension of method for the distal small joints with the new Kinect; stabilize the recognition method as a library.

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References

[1] D. Anton, et al., "KiReS: A Kinect-based telerehabilitation system," in e-Health Networking, Applications & Services (Healthcom), 2013 IEEE 15th International Conference on, 2013, pp. 444-448.

[2] C. Kisner and L. A. Colby, Therapeudic Exercise: Foundations and Techniques, 6 ed.: F.A. Davis Company, 2012.

[3] B. Galna, et al., "Retraining function in people with Parkinson's disease using the Microsoft kinect: game design and pilot testing," Journal of NeuroEngineering and Rehabilitation, vol. 11, p. 60, 2014.

[4] G. Wu and P. R. Cavanagh, "ISB recommendations for standardization in the reporting of kinematic data," Journal of Biomechanics, vol. 28, pp. 1257-1261, 1995.

[5] A. E. F. Da Gama, et al., "Biomechanical Movement Analysis For Upper Limbs Movement Recognition in Real Time," in XXIII Congresso Brasileiro em Engenharia Biomédica, Recife, 2012.

[6] C. Microsoft. (2011). Kinect for Windows. . Available: http://kinectforwindows.org/

[7] H. M. Clarkson, Joint motion and function assessment: a research-based practical guide. Philadelphia: Lippincott Williams & Wilkins, 2005.

[8] A. Da Gama, et al., "Guidance and Movement Correction Based on Therapeutics Movements for Motor Rehabilitation Support Systems," in IEEE Proceedings of XIV Symposium of Virtual and Augmented Reality, Niterói, 2012.