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A Kinect based intelligent e-rehabilitation system in physical therapy

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Abstract. This paper presents an intelligent Kinect and fuzzy inference system based e-rehabilitation system. The Kinect can detect the posture and motion of the patients while the fuzzy inference system can interpret the acquired data on the cognitive level. The system is capable to assess the initial posture and motion ranges of 20 joints. Using angles to describe the motion of the joints, exercise patterns can be developed for each patient. Using the exercise descriptors the fuzzy inference system can track the patient and deliver real-time feedback to maximize the efficiency of the rehabilitation. The first laboratory tests confirm the utility of this system for the initial posture detection, motion range and exercise tracking.

Keywords. E-rehabilitation, Kinect, fuzzy systems, medical rehabilitation

Introduction

Telemedicine or e-medicine is using new generation of intelligent medical devices that have a radical influence on our basic life. These devices in many situations can avoid a potential medical threat [1].

Tele-rehabilitation or e-rehabilitation is an integrated part of e-medicine that enables the patients to realize their rehabilitation therapy at home. In this paper we propose a telerahbilitation system that can monitor the patients that perform a several sets of exercises to correct their posture problems. Posture problems include: scoliosis, lordosis, kyphosis and several other posture deformation that can be solved with medical exercises.

The idea is that the system through the Kinect device monitors the patient movements. If the patient does not follow the exercise pattern than the system displays a message form the patient to correct the movement. At the end of each series the system displays the current status of the patients' progress, evaluate the progress from the last session and predicts a final result. One of the many benefits is that this is done in the comfort of the patient's home.

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Studies shows that patients are more willing to follow through an exercise therapy if they are positively motivated by displaying graphically of their results in form of scores like in the Kinect Adventures game [2].

Recently in this domain several works have been done. One very similar work makes use of the Kinect sensor and a fuzzy enabled a neural network to assess the results of the exercise sets [3]. This system uses Dynamic Time Warping to compare the movements of the patient with prerecorded movements of a chiropractor. One of the main disadvantages of this system is that it does not display an intermediate real time result (ex: if a hand is not raised correctly), but instead it calculates using the fuzzy neural network to calculate a DTW value. According to the DTW value it displays a result at the end of the session without saying why the result is bad or excellent.

Another similar work which makes use of the Microsoft Kinect is the Online-Gym platform [4]. This platform using 2 dedicated servers to create a virtual gym and the users through the Kinect move their avatars. This platform is dedicated to create an exercise and socialization platform for those persons how can't go to a gym due to restricted mobility.

Our system proposes to offer a complete telerahbilitation solution which monitors the patient's evolution in real time and predicts a possible outcome. This solution is not only addressed to patient with restricted mobility but to those patient how can't visit a physical rehabilitation practitioner due to their busy time schedules.

1. Methods

The architecture of the system is presented in figure 1. The system is constructed from a Kinect device, an inference system, several databases to hold specific information about the exercise, posture and the patient evolution. The doctor can monitor the patient's evolution from a distance and set new type of exercises.

1.1. The Microsoft Kinect

The hearth of this e-rehabilitation system is the Microsoft Kinect 3D sensor. This sensor is a cheap yet versatile depth sensor that can detect the posture of the human body [5] and to record the realized movements [6]. Using the 3D coordinates system the human body is represented in form of a "matchstick" skeleton.

The posture of the human body is extracted from the skeleton data by measuring the angles of the joints. These angles are measured by the 2 vector method: where from the joint of interest 2 vectors are traced to two adjacent joints and the angle between the vectors is calculated.

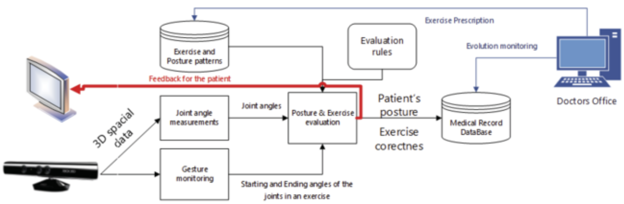

Figure 1. The general architecture of the e-rehabilitation system

1.2. Motion evaluation and exercise description

The Microsoft Kinect SDK recognizes 20 joint points of the human body: HipCenter, Spine, ShoulderCenter, Head, ShoulderLeft, ElbowLeft, WristLeft, HandLeft, ShoulderRight, ElbowRight, WristRight, HandRight, HipLeft, KneeLeft, AnkleLeft, FootLeft, HipRight, KneeRight, AnkleRight and FootRight.
Using the skeletal data from the Kinect sensor and the angle measurements an initial posture and movement range is created for the patient. The physiological movement ranges are the following:

Table 1. Several of the most important physiological motion ranges (angle)

Joint	Minimum	Maximum
Elbow flexion/extension	0	145
Knee flexion/extension	0	140
Shoulder adduction	0	180
Hip extension	15	20

By comparing the current values with the measured values and the distance to the physiological values a prediction can be made on the progress of the physical therapy.

Using the joint angles severel type of exercises can be defined. For each exercise a starting and ending angle of the participant joints must be specified [7]. The following table presents exercise types for using the starting and ending exercise joint angles.

Table 2. Exercises description for sideways stretching to the left

Joints	Starting angle	Ending angle
Hip center	180	180
Hip right	170	1
Hip left	170	100
Knee right	0	0
Knee left	*0*	*0*
Shoulder right	*180*	*180*
Shoulder left	*0*	*0*
Elbow left	*0*	*0*
Elbow right	*180*	*180*

To increase the precision of the description of the exercise the depth coordinate Z will be added.

1.3. The fuzzy inference system

The artificial intelligence (AI) of the system is implemented using fuzzy inference logic. The fuzzy logic extends the Boolean logic by introducing a degree of uncertainty to handle those situations when the Boolean logic fails to produce a correct output. The fuzzy inference system s guided by rules that are similar to the natural language rules.

For each type of evaluation a separate fuzzy inference system must be used. The fuzzy inference systems uses a delta value of the measured angles for evaluation. These delta values represent the distance between the physiological range of motion for a joint and the actual range of motion. A delta value can be calculated with a simple subtraction:

$$\Delta_{Ji} = Ph_{ji} - M_{ji} \quad (1)$$

Where Δ_{Ji} is the distance between the physiological values of the joint (Ph_{ji}) and the measured value (M_{ji})

Several examples of the fuzzy inference rules for the initial joint and posture assessment are the following:

- Joint assessment :
  "IF Elbow_Flexion_Start IS Delta_LOW AND Elbow_Flexion_End IS Delta_High THEN Result IS Severe_Dysfunctionality"
  "IF Elbow_Flexion_Start IS Delta_LOW AND Elbow_Flexion_End IS Delta_Low THEN Result IS Normal_Functionality"
- Body posture:
  "IF Head is Delta_Low AND Neck IS Delta_Medium AND Spine IS Delta_High and HipCenter IS Delta_Medium AND ShoulderRight is Delta_Medium AND ShoulderLeft is Delta_Low Then Result1 IS MediumKyphosis And Result2 IS MinorRightScoliosis"

The fuzzy inference rules for the exercise monitoring are similar to the joint assessment rules but take in consideration all the joints that are necessary to realize the correct exercises. I total over 150 rules were generated

If the patient during the repetitions deviates from the pattern the system will display a graphical warning and a method to correct the current motion as shown in figure 3B.

2. Results and conclusions

To test the system in action several test cases were developed. The first test case was to test the system's ability to detect correctly the posture of the user. In the first case the user was in a normal posture, in the second case the user simulated a kyphosis. Figure 2 presents the results for this test.

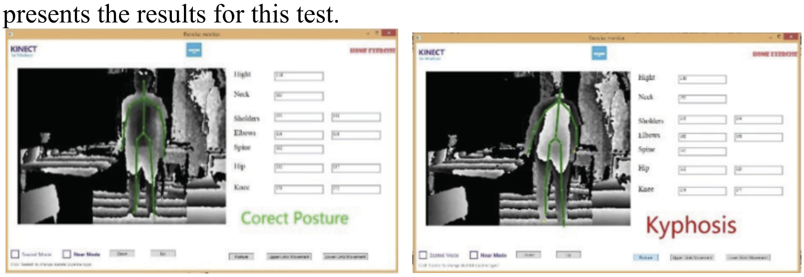

Figure 2. The posture detection test

The second test case was developed to test the systems capability to assess the motion range of the joints. For these test we have chosen the elbows to track if the starting position for a stretching exercise is correct. For this test the flexion and extension movements of the elbow was tested. In case of an incorrect pose the system displays the corresponding message. The results are shown in Figure 3.

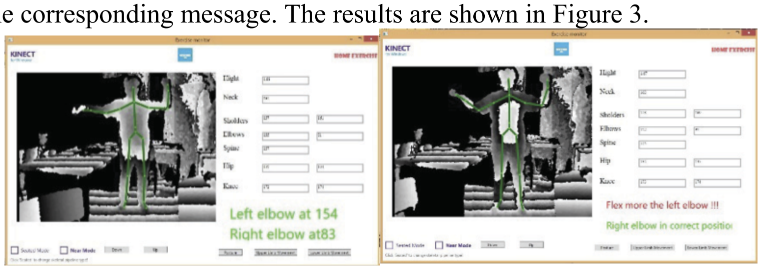

Figure 3. A) Joint angle measurement and B) exercise monitoring

The joint angle tracking showed identical result to the angles measured with a goniometer. The only drawback of the Kinect sensor is that it needs to see the joint and the sensor must be set up individually for each patient.

The clinical trial of the system is in progress. The initial laboratory results show the utility of the Kinect sensor and the fuzzy inference system in medical recovery monitoring and exercise tracking. Using this system the patients can track and visualize their progress which can be a major motivation to complete the medical recovery treatment.

3. Discussion

In comparison with exoskeleton type devices [8] the Microsoft Kinect sensor is a versatile and cheap sensor that can be used in home professional medical rehabilitation processes. Implementing a fuzzy inference system beside the Kinect it provides the so much needed intelligence, so that it can be a peer to the physical chiropractor. This system is in early stages, must be fully tested in clinical trials, but these results are promising. By creating the correct fuzzy rules which take in consideration not just the angles but speed and 3D motion the system can be used at its fullest capacity. With this system the indirect costs of the medical rehabilitation are much lower and the life quality of the patients can be dramatically increased.

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