Analyzing Hand Therapy Success in a Web-Based Therapy System

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Abstract

After an injury, hand therapy should help regaining the full functionality of the hand, wrist and fingers. The application we developed helps a therapist in tracking the success of the therapy. Using the Leap Motion device as a basis, we calculate the individual finger joint angles. A second subsystem measures the angles between the fingers. This data is used to derive a report on the fingers' adduction and abduction during the therapy. The third subsystem detects the wrist rotation angles. Three algorithms were designed to detect the patient hand data, which the system feeds it to the three subsystems, the final algorithm max average error is 5.6 degrees, while the average max error is 9.3 degrees. The web-based system is part of a therapy support system, which allows patients to do their exercise at home and record their individual success.

1   Introduction

Hand therapy is an important field not only because it stops the patient from performing his normal life activities for months, but also because it is a time consuming, boring and costly process. In every year, countries spend billions of euros to cover the hand therapy costs. In 2006, Germany for example, spends 2 billion euro alone from hand severe trauma, while UK spends approximately 130 million euro for hand disorders and finally, USA spends approximately 16 billion euro for treating upper extremity disorders (Dias and Garcia-Elias 2006).

Nevertheless, the therapy usually includes many exercises, which could be considered as boring, and patients do not practice often enough. Moreover, many of the exercises need to be done under the supervision of a therapist who may as well take a measurement of the therapy success before and after each session. These measurements are time consuming in case they include the currently achievable finger joint angles and the finger spread angles which need to be assessed manually by the therapist (Saunders et al. 2015).

Our solution includes a web-based system, which consists of a component that measures the hand, the fingers and the required angle information. The basis for this measurement is the Leap Motion device. Leap Motion is the most powerful and affordable free hand tracking system, which consists of two cameras and three infrared LEDs that allow the device to capture 3D images of the hands. After receiving the raw data, the Leap Motion software filters the image from background objects and reconstructs a 3D representation of the hands. Finally, the software extracts tracking information, including fingers, wrist and elbow (Weichert et al. 2013).

According to the exercises prescribed by the therapist, we defined a selection of dedicated online games and virtual therapy exercises, which integrate these exercises. In this way we intend to provide a more motivating way of making the patient perform the exercises more often (Taylor and Curran 2015)(Szaniawski et al. 2015)(Khademi et al. 2014). Each game or virtual therapy exercise is personalized for each patient automatically according to the last analysis results, where the system automatically sets the angles' thresholds required for each exercise according to the analysis result. Furthermore, during each exercise through the virtual therapy or one of the games, we integrate a module, which measures the progress of the hand during the exercise and stores them in a database. In this way, the success steps of the therapy are immediately visible to both the patient and the therapist. This paper focuses on the measurement methods used to assess the finger angles.

2 Measurements

The first step in diagnosing the patient injury level is to measure the joint angles for each finger in case the patient cannot open or close his hand. In case he cannot spread his fingers or close them, the angles between fingers is measured. While in case he cannot rotate his wrist properly, the wrist rotation angles are measured.

The Leap Motion JavaScript library does not give such information. It only gives the position of bones for each hand, for this reason we had to use the law of cosines to extract the angles' values. Based on that an online web-based module with three subsystems was designed to diagnose the angles. All of these algorithms take 30 measurements in each second.

A visualized hand is shown to the user and therapist to show the current hand state. Furthermore, in the right side of the screen, a number of scroll bars exist to show to the user and the therapist the current value of angles determined from the measurements. Figure 1 shows the first step in the joint angles analysis subsystem.

For the first subsystem that was designed for the joint angles' measurement system, three algorithms were designed. The first algorithm records the hand measurements for three seconds in horizontal position. The second algorithm records the hand measurements for three seconds twice, once in horizontal position and another with flipped horizontal position on the other side of the hand. The third algorithm records the hand measurements for three seconds five times. One for the four fingers Metacarpophalangeal (MCP), one for the four fingers Proximal Interphalangeal (PIP), one for the four fingers Distal Interphalangeal (DIP), one for

the thumb DIP and finally one for the thumb PIP. The hand joint angles' name is shown in Figure 2. At the end of the diagnose a full report is displayed to the user to show for each finger the joint angles, width and length information.
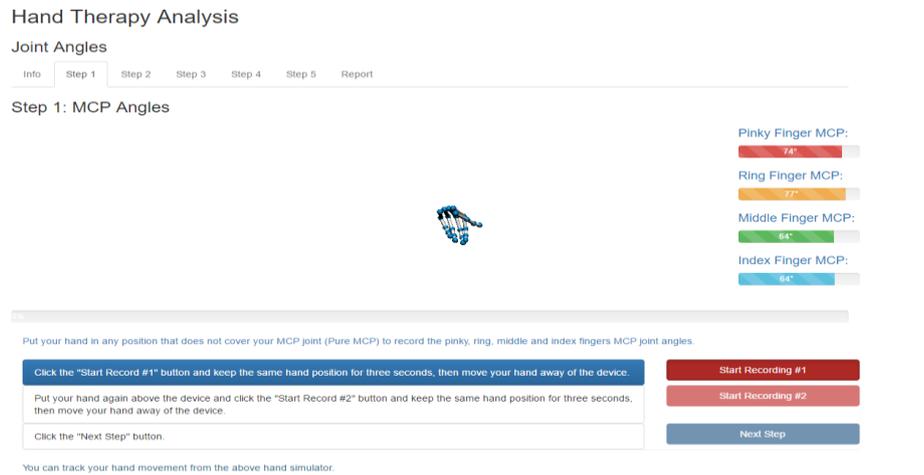

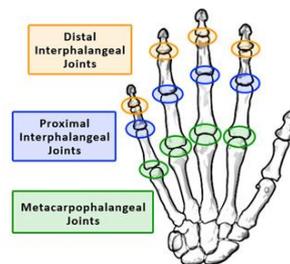*Figure 1: Joint Angles Analysis Subsystem Web-Screen*

Figure 2: Hand Joint Angles' Names

The second subsystem detects the angles between fingers. We only built one algorithm that was sufficient for detecting the angles between fingers, based on the third algorithm for the first subsystem. The algorithm records the angles between the fingers in two steps for adduction and abduction. In each step, it records the data twice and each time for 3 seconds. At the end of the diagnose a full report is displayed to the user to show fingers adduction and abduction information.

The third subsystem detects the wrist rotation angles. We only built one algorithm that was sufficient for detecting the wrist rotation angles, based on the third algorithm for the first subsystem. The algorithm records the wrist rotation angles in six steps wrist flexion, extension, ulnar, radial, pronation and supination. In each step, it records the data twice and each time for 3 seconds. At the end of the diagnose a full report is displayed to the user to show the wrist rotation angles.

3   First Results

In order to analyze the error of our system, we took the measurement of a healthy hand test subject in various positions, including flat, full extension, pure PIP flexion, pure MCP flexion, combined MCP and PIP flexion, full flexion and pinch grip. These measures were collected using the standard measurement method of hand therapy, which is by using an angle ruler, and then we compared it to our system to analyze the max average and average max error in degree.

The max average error for the three algorithms is as follows 9.1, 10.8 and 5.6 degree, while the average max error are 22.9, 20.0 and 9.3 degrees. The reason that the third algorithm gave the best result is because Leap Motion does not give an accurate result when you block it from seeing one of the finger joints. In algorithms, one and two this usually happens when you try to close your hand. However, in the third algorithm we take the measurement of the MCP, PIP and DIP separately. The same concept of the third algorithm was applied in the second and third subsystems, and for this reason, the error is the same in the second and third algorithm as the third algorithm in the first subsection.

In the first analysis subsystem that detects the finger joint angles, the time spent to take the measurement for the three algorithms is 3, 6 and 15 seconds respectively. In the second analysis subsystem that detect the angle between fingers, the total time spent to detect fingers' adduction and abduction is 12 seconds. In the third analysis the subsystem that detects the wrist rotation angles, the total time spent to detect the wrist flexion, extension, ulnar, radial, pronation and supination is 36 seconds.

The three systems were tested on three patients to observe their progress after some periods of hand therapy, and this data was stored in a small database. The test subjects' information is shown in Table 1, as follows:

Number	Age	Gender	Impairments	Hospital
Patient 1	45	Female	cannot close her right hand's joints properly	
Patient 2	45	Male	cannot open his left hand's joints properly	Klinikum Stuttgart
Patient 3	20	Male	cannot move his right hand thumb finger	

Table 1: Test Subjects' Information

Figure 3 shows the progress of the joints' angles for patient number 1. The vertical axes represent the angles in degree, and the horizontal axes in number one represent before starting the hand therapy, number two after 12 hand therapy and number three the data from her healthy hand.
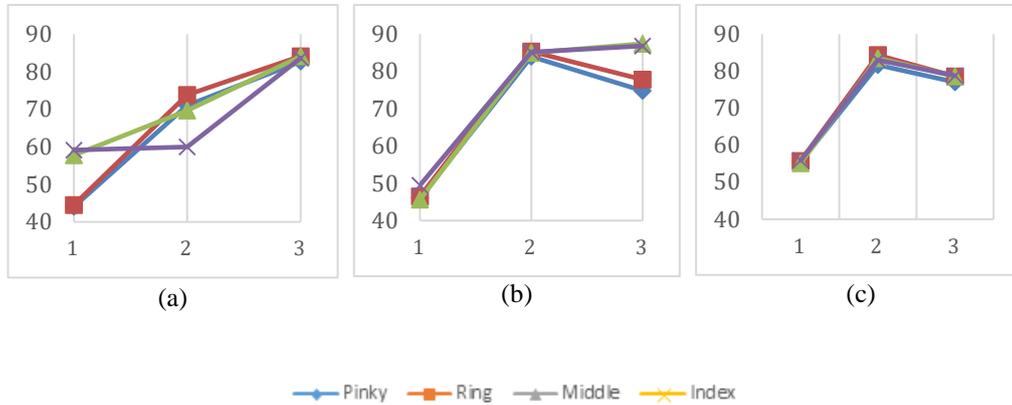
Figure 3: development of angles during the therapy, a recording.
(a)MCP angles, (b) PIP angles, and (c) DIP angles

4 Conclusion

The approaches described above shows the current state of our work in progress and focus on one component of a home therapy system, which will allow patients a more successful recovery from injuries. The first experiments in cooperation with a hospital were done and many more are to follow before the final results of the success of the web-based serious games approach of hand therapy can be published.

5 Future Work

Many tests should be performed on the analysis sub-system before integrating it into the therapy support system. The focus of future tests is to confirm the measurement accuracy and to test it with more patients. The accuracy could be confirmed by comparing our analysis sub-system with the doctor standard measurement method using the angular ruler, while taking measurements with our system to show the progress of the patients to confirm the system applicability in the hand therapy field. Furthermore, multi-sensor fusion using multiple Leap Motion devices could help in increasing the accuracy of the system, by setup one Leap Motion in horizontal position and the other one in vertical position. Another multi-sensor fusion might be by combing Leap Motion with Myo to measure not only the angles but also the force. The result of the analysis could be used to confirm the progress of the patient or to be used to set the thresholds in the virtual therapy and games, that are used to simulate the therapy exercises at home.

Literature

Dias, Joseph J., and Marc Garcia-Elias. 2006. "Hand Injury Costs." *Injury* 37(11): 1071–77.

Khademi, Maryam et al. 2014. "Free-Hand Interaction with Leap Motion Controller for Stroke Rehabilitation." In *Proceedings of the Extended Abstracts of the 32nd Annual ACM Conference on Human Factors in Computing Systems - CHI EA '14*, New York, New York, USA: ACM Press, 1663–68. http://dl.acm.org/citation.cfm?doid=2559206.2581203.

Saunders, Rebecca et al. 2015. *Hand and Upper Extremity Rehabilitation: A Practical Guide*. Elsevier Health Sciences.

Szaniawski, Maciej, Stella Boess, Gerald Kraan, and Richard Goossens. 2015. "Enhancing Engagement with Motor Rehabilitation Therapy through Gamified Rehabilitation Interactions ." In *Design4 Health*,.

Taylor, Jamie, and Kevin Curran. 2015. "Glove-Based Technology in Hand Rehabilitation." 5(4): 29–49.

Weichert, Frank, Daniel Bachmann, Bartholomäus Rudak, and Denis Fisseler. 2013. "Analysis of the Accuracy and Robustness of the Leap Motion Controller." *Sensors* 13(5): 6380–93. http://www.mdpi.com/1424-8220/13/5/6380/.

Authors
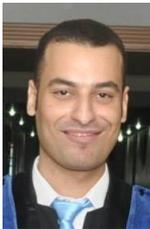
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