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Semi-Automatically Measuring Shoulders' Range of Motion– Objective Measurements with Good Reliability and Accuracy

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Abstract. The shoulder's range of motion (ROM) is an important measurement for the diagnostic process and course of treatment for patients with shoulder disorders or injuries. Visual estimation to assess a shoulder's ROM is a fast measuring method, and therefore routinely used in clinical practice. Studies already proved this method as very subjective and unreliable. Misestimating the severity of a patient's disability can lead to improper treatment and should be avoided. Modern technology may help measuring the ROM more reliable, objective, non-invasive and still fast. In this paper we present a computer-based prototype to semi-automatically assess the patient's shoulder ROM. Still photography is one of the most accurate ways to determine the extent to which a shoulder can be moved. Thus, a marker-less motion sensing device is used to capture movements of patient. A study with n=9 healthy adults was conducted to validate the results of the computer-based system against a physician using goniometry. The results show great potential of this technique for abduction, adduction, anteversion and retroversion with an intraclass correlation coefficient ranging between 0.77 and 0.86 for the best measuring method. Using the system would enhance daily practice. Patients could measure their ROM during their waiting time in advance to the visit, optionally supported by a nurse. Due to the more reliable and objective result the physician can instantly start diagnosing the patient or discussing therapy options. Time for investigation is saved and more time to treat the patient with objective and reliable measurement results would be available.

Keywords. Shoulder, range of motion, active, measurement, Microsoft Kinect

1. Introduction

Measuring the range of motion (ROM) of a joint is a common method in clinical practice. Based on the measurement the diagnosis and the success of the chosen therapy is determined. For example, the shoulder ROM is very important for people's everyday life. Unfortunately, the literature shows a very low interobserver reproducibility of the visual estimation of range of motion of the shoulder [1]. This can cause improper treatment, and therefore should be avoided. The "gold-standard" for measuring shoulder ROM is the radiographic measurement. This method is time consuming and health risking; hence not practicable in a daily clinical routine. Therefore, still photography serves as the gold standard against goniometry. But none of them is as easy as visual estimation which is a widely spread method to achieve the shoulder ROM in clinical practice. Use of technology could help to measure the shoulder range of motion more reliable, objective, non-invasive and still fast.

Several work has been done addressing this problem. Matsen et al. [2] for example showed promising results using the Microsoft Kinect (first version) in a clinically practical method for objectively measured active shoulder motion. Whereas Huber et al. point out that it is imperative to understand Kinect's limitations in precision and accuracy for the measurement of specific joint motions.

In this paper we present our work on the development of a computer-based application system which is able to do shoulder ROM assessment more accurate, reliable and objective than visual estimation, the currently most used measurement method.

2. Methods

For patient's convenience a non-invasive method is desired, to measure a patient ROM. Still photography is one of the most accurate ways to determine shoulder ROM.

Thinking one step further leads to the possibilities offered by video recording techniques and motion analysis. That's why a motion capture system is an important component of our system. A software is used to process the data from the motion capture system. Screen and keyboard are used to see the system's results and for interact.

2.1. Hardware

We used the Microsoft Kinect^{TM} for Xbox One (Kinect). The Kinect is a marker-less motion capture system using a depth camera providing up to 30 frames per second. Furthermore, the Kinect contains a color camera. Each frame with a person in view range contains a simplified skeleton consisting of 25 joints. The skeleton is calculated by the Kinect for Windows SDK 2.0 from Microsoft. These skeleton data provides the basis for the ROM calculation. In particular, the skeleton contains a joint for each shoulder, three joints representing the spine and a joint for elbow and wrist on each body half.

2.2. Software

The software called ShoulderROM is written in C++ and was developed at the institute. During runtime the screen mainly shows the color image recorded by the Kinect like a mirror would do. The image is enriched with data as text at the screen's top and bottom.

The current angles for both body halves are simultaneously measured with four different methods (see next paragraph) and displayed on the screen.

2.3. Measuring methods

In addition to color and depth images the Kinect offers a simplified skeleton representing a person recognized by the marker-less motion-capture system. The simplified skeleton has 25 joints including wrist, elbow, shoulder and three joints representing the spine and more. Each joint equals a single position in three-dimensional space. Those positions are used for further calculations.

Based on explanations for goniometry [3] the stretched spine and the clavicle of a human being are considered as reference bones for shoulder ROM measurement. The upper arm is obviously affected most by the shoulder's motions. One could assume, measuring the angle between upper arm and spine in the Kinect's skeleton would be the best way. The upper arm is described by the shoulder and elbow joints. However, according to [4] the algorithm to estimate skeletons has its weaknesses, especially for precise shoulder positioning. That's why avoiding the use of the shoulder joint was one idea the authors of this paper thought of. If a person fully stretches their arm the forearm is just an elongation of the upper arm. Literature [4] states the detection of elbow and hand wrist is much more precise than the detection of the shoulder joint. Therefore, the forearm could be used instead of the upper arm. Combining the different reference bones results in four potential methods to assess a shoulder angle: i) spine and upper arm, ii) spine and forearm, iii) clavicle and upper arm as well as iv) clavicle and forearm. Considering the bones as vectors the method calculates the angles between arm and reference bones using the scalar product. To ensure good measuring results the movement has to take place in the plane parallel to the Kinect. Due to this simplification leaving out the depth during calculation is reasonable. The movements that have to be performed are abduction, adduction, anteversion and retroversion. The ROM test at Medical School Hannover (MHH) usually includes internal and external rotation both in neutral position (upright stand, arms hanging down next to the body) and with the shoulder abducted to 90 degrees. Because of the Kinect's limitations concepts for measuring rotational movements were not considered in this work.

2.4. Procedure

The validation procedure consisted of several steps. Before starting measurements each subject had to sign a declaration of consent for acquisition and processing of personal data. First the patient performed the movements. Parallel the physician examines the subject's shoulder ROM on each side using goniometry. This procedure was followed by the calibration of the system. That was done by patient standing upright in front of the system for a moment. Afterwards the measuring started. Afterwards the patient performed the same movements themselves in front of the ShoulderROM system like they performed for the measurements by physician. The physician assisted the subject, in case they had problems repeating the movements. The subjects had to stop the movement if they reached their natural movement limit or felt pain. Each subject had to perform each movement twice allowing to measure reproducibility of the measurements by the ShoulderROM system. Four different movements were recorded for each subject on both body sides resulting in eight different motions in total. Finally, the subjects completed a questionnaire assessing the usability and acceptance of the system. The physician used the color images recorded by the ShoulderROM system to measure the ROM with the still photography.

3. Results

The evaluation study was conducted with 9 healthy adults at Hannover Medical School (MHH). All subjects declared having a healthy shoulder. Measuring all movements twice with the ShoulderROM system took five and a half minutes in average. The time was captured from the Kinect recordings between the first and last completed movement.

Including preparation steps like calibration and explanations an additional time overhead has to be considered. This results in an overall duration of approximately ten minutes.

According to [5] reliability of a measurement device equals the extent to which measurements are repeatable. The intraclass correlation coefficient (ICC) is an index to quantify intra- and inter-rater reliability ranging between -1.0 and +1.0. The score between zero and one resembles the amount of reliability in percentage. Less than zero indicates no relationship.

For the method using upper arm and spine the ICC reached values between 0.77 and 0.86 for inter-rater reliability with still photography measurement. The ICC's for the other three mentioned methods were less high. Over 75% of repeated measurements by ShoulderROM deviated less than ten degrees for the same subject.

The usability and acceptance questionnaire showed a high acceptance (3.8 of 5 in average). However, most see problems regarding the autonomous usage. They suggested correcting the user's postures for example by audio commentary. First voice control and then gesture control were the most appropriate or preferable input methods chosen from the users. Two subjects had concerns using ShoulderROM in daily clinical routine. Operating the system by patients alone and the validity of the scores assessed by the ShoulderROM application were viewed just as critically. Other aspects mentioned were repeated wishes for video tutorials and feedback from the system to get instructions and corrections.

4. Discussion

The idea of the ShoulderROM project [6] is the development of a computer-based application system able to do shoulder ROM assessment more accurate, reliable and objective than the currently often used measurement method of visual estimation.

The Microsoft Kinect^{TM} for Xbox One is used as a marker-less sensing device. Therefore, patients need no additional clothes to do the measurement, but loosely fitted clothes should be avoided since they can cause faulty measurements. In general, the depth tracking is suited for this application. However, the skeleton tracking by the Kinect SDK has limits and problems of tracking special poses, especially when joints conceal each other. This specially effects the inner and external rotation. Which is why they were excluded from this development.

One of the four methods to assess the ROM semi-automatically revealed promising results on accuracy and reliability: The combination of upper arm and spine worked best.

The system acceptance by users was rather high. Nevertheless, there were doubts concerning the acceptance in a less technical interested user group. In case users cannot operate the system correctly the software should provide instructions or personal support should be available to ensure valid results.

Readers should keep in mind that the number of nine subjects testing this system is rather small and therefore not significant. Furthermore, only one physician measured the ROM in comparison to the system.

There still remain some challenging tasks like interaction with patients. The system has to ensure the patient understands the instructions and uses his full range of motion. One possibility to solve this challenge is a backup nurse, which may assist if help is needed. Aside from challenges there is a big benefit: The system could avoid errors introduced in documentation by human failure. Until now, ROM data is not stored systematically. The system could document the measurement results in the patient's record automatically. Apart from a better insight in the therapy progress this would enable research on ROM data which was not possible before.

5. Conclusion

In general, it is feasible to develop a computer-based application system able to do shoulder ROM assessment more accurate, reliable and objective than the currently most often used measurement method. Examining a patient ROM during waiting time with technology has several advantages. Most important is a reliable and objective measurement. Additionally, the physician saves time during the appointment. The chance of misestimating the severity of a patient's disability, and thus prescribe improper treatment may be reduced.

To facilitate this in clinical routine researchers and physicians have to face two major challenges. The system must be reliable, accurate and objective against the gold-standard for all types of movements and all types of shoulder movement limitations. Apart from the accuracy the system should be suited for a wide range of possible users with different technology background. It should give instructions and correcting hints. An additional benefit for routine and research could be automated documentation of the results in our healthcare system.

References

[1] Terwee CB, Winter AF de, Scholten RJ, Jans MP, Devillé W, van Schaardenburg D, Bouter LM. Interobserver reproducibility of the visual estimation of range of motion of the shoulder. Arch Phys Med Rehabil. 2005;86:1356–61.

[2] Matsen FA, Lauder A, Rector K, Keeling P, Cherones AL. Measurement of active shoulder motion using the Kinect, a commercially available infrared position detection system. J Shoulder Elbow Surg. 2016;25:216–23. doi:10.1016/j.jse.2015.07.011.

[3] Reese NB, Bandy WD. Joint Range of Motion and Muscle Length Testing. 2nd ed. London: Elsevier Health Sciences; 2013.

[4] Shotton J, Sharp T, Kipman A, Fitzgibbon A, Finocchio M, Blake A, et al. Real-time human pose recognition in parts from single depth images. Commun. ACM. 2013;56:116. doi:10.1145/2398356.2398381.

[5] Carter RE, Lubinsky J. Rehabilitation research: Principles and applications. St. Louis Missouri: Elsevier; 2016.

[6] Ilonka Pingel. Shoulder Range of motion assessment using a motion sensing device [Master's thesis]: University of Braunschweig - Institute of Technology and Hannover Medical School; 05/2016.