Using Computer Vision-based Markerless Pose Estimation for Measuring Shoulder Range of Motion

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***Abstract*— The use of health technology applications has increased during recent years among health care professionals. A novel and innovative approach for implementing health technologies in daily practice is through Computer Vision (CV) based markerless pose estimation. This approach is useful especially in rehabilitation applications for providing automatic guidance for clients performing rehabilitation exercises. The aim of this paper is to present the technical realization and early stage testing results of an open source prototype application for shoulder Range of Motion (ROM) analysis for rehabilitation purposes. The testing process included early stage accuracy tests of the prototype, in comparison to using a universal goniometer, for measuring all four active motion movements of the shoulder (flexion, extension, abduction, adduction). The results indicated that CV-based markerless pose estimation has the potential to accurately analyze shoulder joint ROM. In conclusion, the markerless CV application used in this study was found to have potential to be used in clinical practice by healthcare professionals. However, more comprehensive testing is still needed before it can be put into practice.**

Keywords- computer vision; range of motion; telerehabilitation; YOLO.

I. Introduction

The use of health technologies has been more frequent in recent years due to the COVID-19 pandemic, and enforced health care organizations to integrate Telerehabilitation (TR) into daily routines in clinical work [1]. Also, ensuring convenient and equitable access to health care services poses a notable challenge, given factors such as the aging population, rising incidence of chronic diseases, and the centralization of health, rehabilitation, and social services in urban areas [2]. TR is defined as a health care service that is delivered to clients through Information and Communication Technology (ICT) [3]. In physiotherapy, TR enables clients and health care professionals (physiotherapists) undergoing rehabilitation to connect from various locations, and stay in contact in real-time or asynchronous communication through ICT. However, it can also mean health technology applications that gives automatic information and support for the client [4].

There is evidence suggesting that TR could be as effective as and comparable to traditional physiotherapy in various diseases, such as rehabilitation following Parkinson's disease [5], heart diseases [6], non-specific chronic low back pain [7], stroke [8] and hip arthroplasty [9]. A benefit compared to traditional physiotherapy is that clients undergoing rehabilitation do not have to travel for TR, which increases the accessibility, whether influenced by the geographical location of clients or constraints within health care services [10]. There is also some evidence that TR is a more cost-effective method than traditional physiotherapy at a clinic [7].

A novel and innovative approach for implementing TR in daily practice in rehabilitation is through Computer Vision (CV) based markerless pose estimation. Pose estimation systems provide keypoint detection which can be utilized for detecting and locating joints of the human body. Based on estimated joint coordinates for each frame, different types of joint Range of Motion (ROM) assessment can be automatically performed.

Tracking and analysis of human movements using CV have been an important research topic for years [11]. CV typically employs marker-based methods, requiring placement of markers as reflective material on crucial body points (key points) like finger, elbow, shoulder and hip joints [12]. This limitation reduces the regular use of CV motion analysis systems impractical, as it requires extensive technical preparations before the use.

The benefit of using markerless pose estimation is that the only technical equipment needed is a regular computing device, such as laptop or smartphone, equipped with a camera. Several markerless pose estimation systems have been proposed and evaluated for rehabilitation purposes [13]. Most systems provide 2D joint detection using a single external web camera setup. Some solutions also provide 3D joint detection, by utilizing multiple camera views, providing the possibility to perform more advance ROM assessments.

However, markerless pose estimation systems bring some challenges that must be addressed before they can be integrated into rehabilitation practices. The main challenge is the necessity to establish sufficient accuracy of the measured data [14].

The aim of this paper is to introduce a novel markerless CV-based prototype application for measuring shoulder joint ROM for rehabilitation purposes and to preliminary validate its accuracy through early stage testing. The prototype requires only a single web camera and an off-the shelf laptop or desktop computer. The early stage testing procedure has been committed to an interdisciplinary research team, comprising experts from both physiotherapy and information technology. The structure of the rest of the paper is as follows. Section II introduces the new CV-based markerless prototype application and its technical features. Section III describes the early stage testing process and preliminary results. In Section IV, strengths and limitations of the prototype are discussed. Finally, some conclusions and future research directions are presented in Section V.

II. Prototype Application for Computer Vision-Based Markerless Shoulder Joint Range of Motion Measurement

A new prototype application for measuring shoulder joint ROM using a CV-based markerless technology was developed with both measurement accuracy and user accessibility taken into priority. To be able to achieve reliable ROM analysis, the shoulder, elbow, and hip joints must be located accurately. For detecting human joints, without using physical markers, a deep learning based key point detection methodology is needed which is typically computationally resource intensive.

You Only Look Once version 8 (YOLOv8) [15], however, is a popular object detection technique due to both its accuracy and speed which makes it advantageous for real time detection on a wide range of computation devices. YOLOv8 includes a pose estimation model, pretrained on the COCO dataset [16], that provides human body keypoint detection.

The keypoint detection feature of YOLOv8 was utilized in the prototype application for detecting and localizing the hip, shoulder and elbow joints for each frame. Hence, shoulder ROM analysis is performed by measuring and analyzing the shoulder angle α, Figure 1.

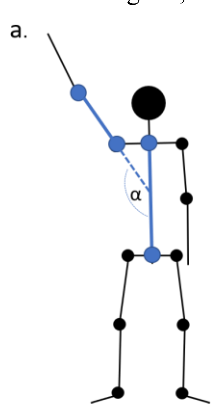

Figure 1. The shoulder angle α measured by the prototype a) from the front and b) from the side.

When assessing shoulder abduction and adduction, the client is standing with the front towards the camera (see Figure 2) and α is defined as the angle between the shoulder-elbow line and the midline of the body. The start and end point of the midline are estimated by calculating the center point between the shoulder and the hip joint pairs.

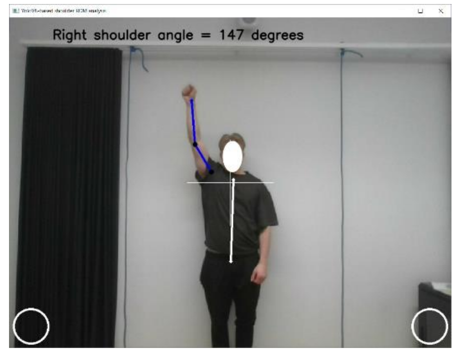

Figure 2. A screenshot of the prototype application when performing shoulder abduction and adduction assessment.

Correspondingly, when assessing shoulder flexion and extension the client stands with either side facing towards the camera, see Figure 3.

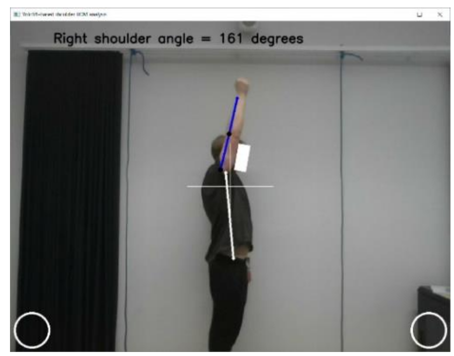

Figure 3. A screenshot of the prototype application when performing shoulder flexion assessment.

The shoulder angle α is in case of shoulder flexion/extension defined as the angle between the shoulder-elbow line and the shoulder-hip line.

III. Early Stage Testing

Early stage testing was conducted to compare the prototype application with Universal Goniometer (UG) when measuring shoulder joint ROM (flexion, extension, abduction and adduction) in standing position. UG was chosen as a reference for our CV prototype application as it is the most frequently used method by healthcare professionals for this purpose [17]. We followed the instructions by [18] when using bony landmarks for the UG measurement. UG measurements were performed by an experienced physiotherapist. The shoulder joint measurements were conducted in a standardized order: active flexion, active extension, active abduction and active adduction. Environmental factors were standardized as follows: White background and bright lightning were used in the test room. The distance between the test participant and the integrated laptop web camera was 2.85 m and the camera was positioned 1.35 m above the floor level. The test room and setup are shown in Figure 4.

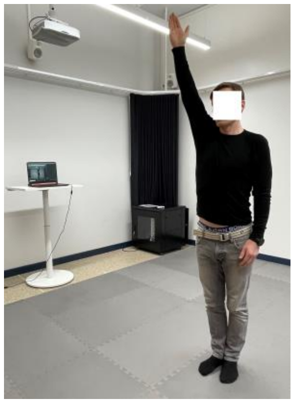

Figure 4. Picture of test setup when a participant performs active flexion in shoulder joint.

Three healthy voluntary persons over the age of 18 participated in the early stage test. All measurements were documented in a blind way, and each joint angle, measured by the prototype application, was stored in a log file with a timestamp. This information remained confidential until the corresponding angles were measured manually with UG. The angles were measured in whole degrees in the following order: 1) active shoulder flexion, 2) active shoulder extension, 3) active shoulder abduction and 4) active shoulder adduction.

All measured angles and measurement differences between the prototype application and UG are documented in Table I.

TABLE I. MEASURED ANGLES OF ACTIVE SHOULDER RANGE OF MOTION AND MEASUREMENT DIFFERENCES BETWEEN THE COMPUTER VISION (CV) PROTOTYPE APPLICATION AND UNIVERSAL GONIOMETER (UG)

Movement direction and difference	**Person 1**	**Person 2**	**Person 3**
Active shoulder flexion[a], CV	169	171	172
Active shoulder flexion[a], UG	170	170	175
Difference[a]	-1	1	-3
Active shoulder extension[a], CV	57	55	65
Active shoulder extension[a], UG	53	55	59
Difference[a]	4	0	6
Active shoulder abduction[a], CV	163	172	164
Active shoulder abduction[a], UG	170	165	170
Difference[a]	-7	7	-6
Active shoulder adduction[a], CV	17	14	17
Active shoulder adduction[a], UG	20	20	17
Difference[a]	-3	-6	0

[a]Values in degrees

IV. DISCUSSION

This paper has introduced a novel CV-based markerless prototype application for shoulder ROM analysis and presented preliminary accuracy evaluation results based on early stage testing. The prototype application performed the measurements with a moderate level of accuracy in all four active motion movements (flexion, extension, abduction, adduction).

Even though the measurements performed by the prototype application were not exactly equivalent with the manual UG measurements in this early stage test, the results can be considered promising. This, due to the fact that UG, that is the mostly used measurement tool by healthcare professional in daily practice, has showed a measure error of 6°. The use of radiograph images is the most accurate method for measuring the joint angle [19], however, due to ethical reason and high costs, this method was not used.

We recognize that the lightning in the room where the measurements were conducted influenced the results and how well the joints were detected by our prototype application (accuracy tends to decrease in darker environments).

V. CONCLUSION AND FUTURE WORK

CV is a promising technique for TR as it can be used for human motion analysis and show results to clients in real time without the need for complicated equipment. However, the accuracy of the joint detection capabilities of the motion analysis system is crucial in order to be able to provide a reliable motion analysis.

In this paper we have introduced a novel CV-based prototype application for measuring shoulder joint ROM. Early stage testing results indicated that our novel prototype application, using a CV based markerless pose estimation model, has potential for providing reliable shoulder ROM analysis. However, before a reliable accuracy level can be confirmed, and before CV based markerless pose estimation ROM analysis can be integrated in clinical practice, more comprehensive tests must be conducted. Therefore, future work should focus on testing the accuracy of the prototype application by performing measurements on a large group of persons, both healthy test persons but also on persons with different types of upper limb symptoms. Furthermore, tests must be conducted in environments with variable backgrounds and lightning conditions to ensure that the technology is suitable also for home use and not only in standardized environments.

YOLOv8 provides several different pre-trained models for pose estimation with different levels of accuracy and computational cost. These different versions should also be more rigorously tested for finding a suitable balance between usability and accuracy.

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