Title:
Assessment of Patient's Injured Shoulder Based on Digital Motion Acquisition

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Introduction:
Orthopedic physicians and physiotherapists deal with rehabilitation processes during which several assessments have to be done to evaluate patients' progress. Usually, medical personnel assess the improvements through the evaluation of rehabilitation exercises he/she has to do for recovering the physical abilities after an injury or a surgery. Nowadays, the medical evaluation is based on several parameters relative to medical knowledge, which are consolidated by the experience obtained during daily practice but heavily depends on the physicians' subjectivity.

In such a context, technology, such as Motion Capture (Mocap), can represent a valid solution; in fact, human motion tracking is creating new frontiers for potential clinical and home applications. Several inexpensive sensors and software platforms are available; in particular, markerless systems based on low-cost RGB-D sensors, such as Microsoft Kinect v1 and v2, have been adopted both in industrial and medical sectors [2-4]. The most important step is the domain-dependent data elaboration, which is the bottleneck of the entire process. A multidisciplinary approach is needed to understand which are the right parameters, when they must be considered, and to interpret the results so that final users can be provided exactly with the information they need. In previous works, a general methodology and some applications of rehabilitation supported by motion acquisition technologies were carried. The methodology [10] has a general value and each application differs in terms of (i) Mocap set-up and (ii) data elaboration, depending on the body segment involved and activity performed.

This paper reports the research activities carried out to investigate the application of a Mocap-based methodology for shoulder articulation. The complex movements of a shoulder are difficult to be captured and, moreover, the skeleton models often oversimplify shoulder articulation with just a rotate joint. Thus, the paper shows the way different acquisitions and elaboration techniques have been integrated to allow a quantitative evaluation of shoulder rehab exercises.

Main Aim:
This research works aims at defining a specific technical solution for the application to the shoulder rehab. To quantitatively assess shoulder performance after a trauma or a surgical procedure, low-cost Mocap systems and image processing techniques have been integrated.

Methodology:
The methodology comprehends five steps [10]:

- Knowledge acquisition: at first interviews to domain experts are required to collect and formalize rules and guidelines related to the specific activity (e.g., how to perform exercise and evaluation parameters).

- Mocap system setup. This step consists in defining the relevant set up for the acquisition phase. According to the kind of exercise or task that must be seen by the sensors, an optimal acquisition volume is defined.
- Motion acquisition. This is the most repetitive part and it can be performed almost in the same way for any kind of applications.
- Knowledge elaboration. This is the most challenging step since it has the goal to translate guidelines and rules into algorithms able to extract the right information from the Mocap data.
- Data elaboration. This last step has the goal of performing, in the most automated way, the elaboration of data to gather the requested output.

The next sessions describe the application of the methodology to verify the technical feasibility of the proposed solution. In particular, after the first two steps we focused the attention on the motion acquisition and knowledge elaboration, which are most critical ones due to the complexity of the shoulder articulation.

Knowledge Acquisition

The medical knowledge has been acquired through the collaboration with a rehabilitation center and relevant scientific literature [5], [9]. A shoulder articulation comprehends three bones, i.e. scapula, clavicle and humerus. Furthermore, there are many muscles and tendons connected to these bones, which are activated in a very complex way for performing movements. One of the basic movements of a shoulder articulation, is obtained through the abduction of the arm. The abduction exercise consists in rising the extended arm on the frontal plane from the rest position along the body (Fig. 1(a).) to a horizontal position (Fig. 1(b).) and up to the limit the patient can reach (Fig. 1(c).). Therefore, the aim is to evaluate the abduction performed with the injured shoulder, which is strictly correlated with a movement performed by the scapula (namely scapular elevation).

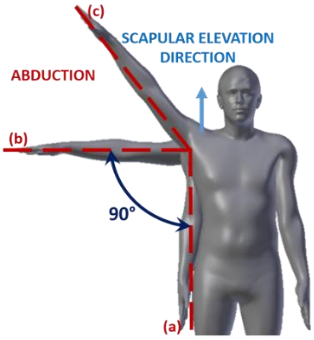

Fig. 1: Abduction exercise.

The arm abduction is correctly executed if there is no scapular elevation before 90° are reached. According to physiotherapists' experience, we consider that the shoulder elevation is neglectable if lower than 2 cm (Fig. 2.).

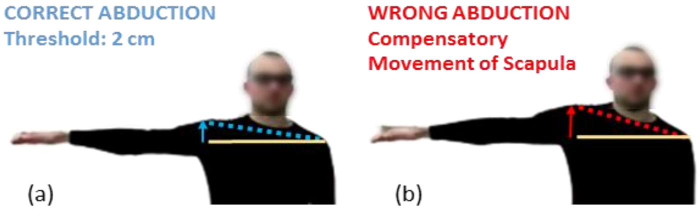

Fig. 2: Correct abduction (a). Wrong abduction (b).

The scapular elevation involves different muscles that should not be used for executing abduction movement. This situation happens because the patient has pain when he/she moves the injured shoulder using correct muscles for abduction. Thus, the reason for shoulder rehabilitation is relative to the re-activation of all muscles for executing basic movements in an as natural as possible way.

MOCAP System Setup
In order to track the abduction of an arm, the adopted Mocap system has been configured with a single RGB-D Microsoft Kinect v2 sensor since the movements are only in the frontal plane. The device has been positioned in front of the patient. A distance of 270 cm and 122 cm of height allow a correct acquisition of movement performed with arms by a person.

Motion Acquisition
Ipi Soft Suite [6] has been used to manages data acquired with Microsoft Kinect v2 device. The measurement of scapular elevation can be done by considering the vertical translation of the virtual clavicle joint on the frontal plane.

During preliminary acquisitions, an important limit has been observed. The used system was not able to properly detect the movement of the shoulder and measure the scapular elevation. Fig. 3. shows an acquisition of an abduction in which the virtual skeleton has been generated by starting from human body point cloud. Fig. 3(a). is relative to the instant before performing the abduction in which the position of the clavicle joint can be considered overlapped to the real one. Fig. 3(b) depicts the abduction performed in a wrong way, i.e. rising the shoulder too early. The point cloud highlights the presence of a high scapular elevation, but the position of the clavicle joint is remarkably lower.

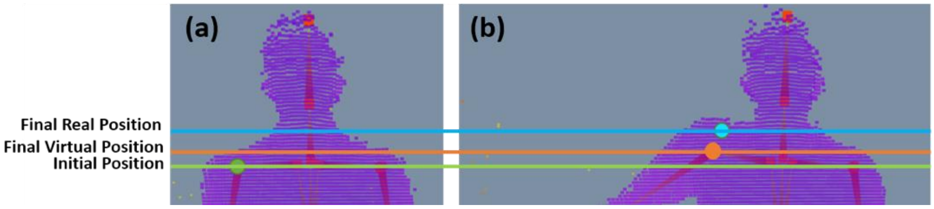

Fig. 3: Abduction performed in a wrong way. The virtual avatar does not follow the real movement.

Technological limits: how to improve the accuracy of recorded abduction
To solve the above-mentioned problem, RGB images and 3D point cloud of the Microsoft Kinect v2 device can be used in an alternative way for motion tracking. We developed a procedure, which exploits RGB data (i.e., the recorded video) to find the vertical translation of scapular elevation through a tool for motion tracking. 2D motion tracking is possible through video processing algorithms that are used to detect movements of simple shapes (e.g., a square or a circle). Blender has been chosen as open-source software for 2D motion tracking [1]. It makes available a powerful motion tracking tool, which is able to detect 2D translational movements of a selected object in a video. Furthermore, the tracked movement can be associated to a 3D object if the camera's position is known, as happens in our case. The acquisition based on iPi Soft Studio allows to automatically calibrate position and orientation of the used device. The camera data can be used in Blender for creating a virtual camera with the same features. Then, the motion tracking tool exploits this 3D camera's information for computing the 3D motion of the tracked object. Finally, the 3D motion can be associated to an existent 3D object as the clavicle joint of the animated skeleton, that can be imported in Blender in BVH file format.

By starting from this tool of Blender, the new procedure is shown in Fig. 4. First, a simple square of white adhesive tape is applied on the extremity of the injured shoulder as tracking marker. The marker is located near the acromial end of the real clavicle because its movement reproduces what happens during the execution of abduction. Then, the Mocap acquisition can be executed by using iPi Recorder and the Kinect v2 device. At this point, both video and depth data are used by iPi Soft Studio for creating the initial virtual skeleton. The scapular elevation is detected through the 2D motion tracking tool of Blender, which automatically detects and tracks the white marker previously positioned.

After the execution of 2D tracking, the virtual camera is created in Blender according to its position and rotation computed in iPi Soft Studio. The translations of the white marker, which follows the movement of shoulder, is used as trajectory of the clavicle joint. Then, the initial virtual skeleton is imported in the 3D environment of Blender and the tracked trajectory is associated to clavicle joint through a Python module executed in Blender. The modified animation is exported by Blender to be used as input data in an application developed in Python. The developed application evaluates the abduction movement according to embedded medical knowledge.

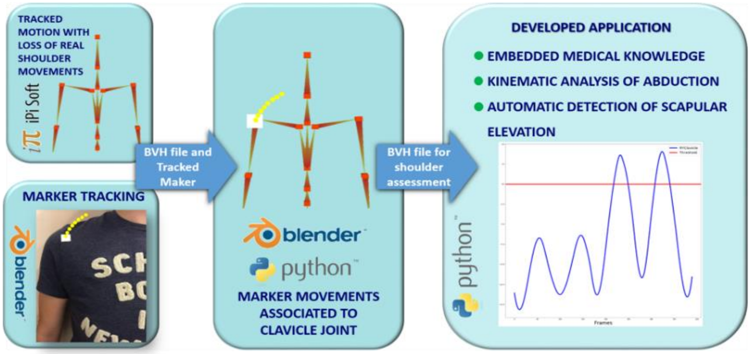

Fig. 4: Workflow of new technological solution.

Preliminary Test:
A preliminary test campaign has been performed for validating the procedure. A physiotherapist has been involved for the medical assessment and fifteen engineering students as testers. Each student has been asked to execute a simple shoulder rehabilitation exercise composed by 4 abductions, the first two done in a correct way and the last two rising the shoulder before 90° rotation (i.e., performing a wrong movement of the scapula). During the Mocap acquisitions of each tester, the physiotherapist evaluated the abduction movements through the traditional observational method and his assessments were compared with the results automatically calculated with the proposed solution. Tab. 1. shows the maximum scapular elevations, i.e. the vertical translation of the scapula (measured in cm), reached by each tester during the execution of the four abductions.

		Testers														
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Scapular elevations (cm)	**Abd. 1**	1,2	1,4	1,3	1,4	1,2	1,3	1,4	1,3	1,1	1,4	1,1	1,6	1,5	1,6	1,5
	Abd. 2	1,1	1,3	1,2	1,2	1,4	1,4	1,6	1,7	1,2	1,2	1,3	1,6	1,4	1,3	1,6
	Abd. 3	2,5	2,3	2,6	2,8	2,2	2,8	2,9	2,7	2,5	2,7	2,6	2,3	2,2	2,8	2,6
	Abd. 4	2,7	2,5	2,4	2,5	2,7	2,9	2,7	3,1	2,9	2,9	2,8	2,7	2,8	2,6	2,8

Tab. 1: Maximum scapular vertical elevations during abduction exercises.

We can note that all the exercises performed in the wrong way, according to the physiotherapist, have been correctly evaluated as "wrong" (red cells) by the application (abduction 3 and 4). About abductions 1 and 2, which are correctly executed for the physiotherapist, the system classifies them in two groups. The first group is relative to exercises, which are clearly performed in a correct way (green cells) and the measurements is significantly under the threshold value (in this case below 1.5 cm). The second group are exercises the physiotherapist has evaluated correctly performed, but the measured value is too near to the threshold for being surely considered correct. This group of values are highlighted to give a warning to the physiotherapist about potential critical conditions.

The accuracy of low-cost makerless Mocap systems have been evaluated. Some research works demonstrated that low-cost markerless systems measurements of patient's movements are good enough for rehabilitation purposes [7]. In fact, several comparisons among low-cost and high-end devices are reported in literature. For example, Otte et al. [7] used simultaneously a single Kinect v2 device and a Vicon system to record movements of arms during six different movement tasks. The accuracy of Kinect V2 landmark movements was considered good to optimal, depending on movement dimension and performed task. In general, literature shows a good acceptance of low-cost solutions applied to rehabilitation. Moreover, despite the systematic error that may be due to the sensing devices adopted, the solution has to be tuned comparing results with physiotherapist assessment in other to determine the exact threshold for discriminating good movements from bad ones.

Finally, a limit has been highlighted relative to the use of a white square marker applied on the extremity of the clavicle. This approach can be considered invasive by the patient as well as other physiotherapists could consider the positioning of marker too approximate to properly detect the scapular elevation.

Conclusions:

This research work presents a novel application based on low cost Mocap system to assess rehabilitation processes of trauma or post-surgery shoulder. The new solution exploits the acquired data to track desired movements through the introduction of a new software as Blender. Blender uses image processing algorithms that can be fruitfully exploited for improving the accuracy of movements acquired with both RGB and RGB-D sensors. The solution has been tested and the preliminary results have been considered very promising by the involved medical personnel. In particular, the physiotherapist highlighted the importance of having objective measuring that can be used for monitoring patients' improvements along rehabilitation processes. Furthermore, he suggested this software tool as starting point to better evaluate errors done by patients during rehabilitation exercises, such as back curvature during abduction, scapular elevation correlated with pain and adduction evaluation. Further developments have been planned to improve the presented solution and solve emerged problems. Finally, the developed method uses open-source software and then, it puts the base for the development of a single software application, which will permit the medical assessment of shoulder in automatic way by starting from kinematic data of a Mocap system.

References:

[1] Blender, https://www.blender.org/.

[2] Dutta, A.; Chugh, S.; Banerjee, A.; Dutta, A.: Point-of-care-testing of standing posture with Wii balance board and microsoft kinect during transcranial direct current stimulation: a feasibility study, NeuroRehabilitation, 34(4), 2014, 789-798. https://doi.org/10.3233/NRE-141077

[3] Dutta, T.: Evaluation of the Kinect™ sensor for 3-D kinematic measurement in the workplace, Applied Ergonomics, 43(4), 2012, 645-649. https://doi.org/10.1016/j.apergo.2011.09.011

[4] Huber, M. E.; Seitz, A. L.; Leeser, M.; Sternad, D.: Validity and reliability of Kinect skeleton for measuring shoulder joint angles: a feasibility study, Physiotherapy, 101(4), 2015, 389-393.

[5] Imhoff, A. B.; Beitzel, K.; Stamer, K.; Klein, E.: Shoulder: rehabilitation, in Rehabilitation in Orthopedic Surgery, Springer, 2016, 27-60. https://doi.org/10.1007/978-3-662-49149-2_3.

[6] iPi Soft, http://ipisoft.com/

[7] Mousavi Hondori, H.; Khademi, M.: A review on technical and clinical impact of microsoft kinect on physical therapy and rehabilitation, Journal of Medical Engineering, 2014. https://doi.org/10.1155/2014/846514

[8] Otte, K.; Kayser, B.; Mansow-Model, S.; Verrel, J.; Paul, F.; Brandt, A. U.; Schmitz-Hübsch, T.: Accuracy and reliability of the kinect version 2 for clinical measurement of motor function, PLoS ONE, 11(11), 2016, e0166532. http://doi.org/10.1371/journal.pone.0166532

[9] Reed, D.; Cathers, I.; Halaki, M.; Ginn, K. A.: Shoulder muscle activation patterns and levels differ between open and closed-chain abduction, Journal of Science and Medicine in Sport, 21(5), 2018, 462-466. https://doi.org/10.1016/j.jsams.2017.07.024. Blender, https://www.blender.org/.

[10] Regazzoni, D.; Vitali, A.; Rizzi, C.; Colombo, G.: A method to analyse generic human motion with low-cost mocap technologies, ASME. International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, 1(B). https://doi.org/10.1115/DETC2018-86197.