Title:
Assessment of Spinal Cord Injured (SCI) Patients Based on Digital Motion Acquisition

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Introduction:
The rehabilitation process of post-injury patients requires a continuous monitoring by medical personnel, who has to understand if rehab exercises have been executed in correct way by the patient to improve his/her motoric conditions.

At present, the assessment is based on several parameters well known in literature and on subjective knowledge of the physician, who bases evaluations on his/her experience. The subjectivity of an evaluation may affect the steps of the rehabilitation process and this usually happens when the medical personnel is composed by young practitioners with not enough experience or when the assessment has been done by different physicians with discordant points of view.

Another bottleneck in the assessment of rehabilitation process is relative to inaccurate measurement of parameters useful for evaluating patient's improvements. Usually, medical personnel measure improvements through a visual evaluation, which permits only to identify huge improvement or worsening. However, some research works highlight that small errors relative to postures and use of upper and lower limbs can create problems in the long term [5], [9].

This is the case in rehabilitation processes relative to patient who have been subjected to spinal cord injury (SCI). SCI patients follow a precise rehabilitation workflow that comprehends their motor capability and the learning process about the use of wheelchair in order to live in autonomous way. A wrong use of the wheelchair creates harms to the patient, such as pain in arms and shoulders as well as bedsores along legs and back.

Several medical feedbacks report about the possibility to introduce innovative technology, which can be used as instruments to make the assessment of the rehabilitation process more objective and easy for medical personnel. Furthermore, the use of technology allows measurements more detailed to evaluate rehab exercises. In literature, motion capture (MOCAP) systems are shown as technological solutions for facing these issues. According to the working principles, Mocap solutions are usually grouped in four main categories: mechanical, inertial, magnetic and optical.

Among several types of MOCAP solutions, optical Mocap systems are increasingly exploited for human motion analysis in medical assessments relative to both analysis of the correctness and completeness of motions after surgeries and evaluation of rehabilitation paths. Optical systems consist of cameras as well as other optical sensors to track light sources or reflections or to detect profiles from video frames. At present, the most growing solutions are infrared cameras and marker-based systems, such as Vicon [13] and Qualisys [12]. Furthermore, marker-less based systems belong to this last category. Their low-cost and ease of use make marker-less MOCAP systems an interesting base for innovative solutions. Marker-less MOCAP systems are composed by RGB-D cameras. This technology is attracting the interest of both research and medical communities. The most diffused are Microsoft Kinect v1 and v2. Literature reports applications in several medical contexts, for example for virtual ergonomics [7] and preventing of musculoskeletal diseases (MSDs) [1],[4] or for evaluating rehabilitation exercises [1], [11], or for monitoring different disability as strokes [14] and elderly [3]. Moreover, research works have been done to assess accuracy and reliability of Microsoft Kinect v2 in medical contexts and the reached results have been considered adequate for both technical and medical personnel [10].

This research work presents the use of a low cost MOCAP system to evaluate the use of wheelchair by SCI patients during their rehabilitation processes. First, we introduce the main aim of the research work, then, the designed solution is described and clinical tests carried out with an Italian Hospital is discussed. Finally, results and further developments are summarized.

<u>Main Aim:</u>
This research work aims at presenting the use of a marker-less motion capture system to evaluate rehabilitation process of SCI patients. The developed solution exploits data acquired by the MOCAP system as input data of an ad-hoc developed knowledge guided application. This application embeds a set of medical rules that combined with acquired data makes available a set of medical information useful for an objective evaluation of the use of patient's wheelchair.

<u>Designed Solution:</u>
The proposed solution is based on a low-cost maker-less MOCAP system composed by three devices Microsoft Kinect v2, each connected to a laptop. The MOCAP data are acquired and managed through the commercial software platform iPiSoft which is composed by two software tools: iPi Recorder and iPi Mocap Studio [6]. The first one records data acquired by all connected Kinect devices (Fig. 1.(a). and Fig. 2.(b).) and iPi Mocap Studio manage raw acquired data in order to create virtual avatar and cinematic data which will be used as input of developed application (Fig. 1.(c).).

(a) (b) (c)

Fig. 1: Depth data (a) and RGB data (b) acquired with Kinect devices through iPi Recorder. Related virtual avatar computed by iPi Mocap Studio (c).

Layout of MOCAP system
The layout of the MOCAP system has been an important issue. In order to monitor SCI patients and their wheelchairs' use, the distance of the horizontal path has to be more than 6 meters long. On the other side, the calibration of MOCAP system requires all Kinect devices are able to detect the light marker during the recording and thus, the distances among Kinect devices have to guarantee a calibration zone in which the light maker can be detected by all Kinect devices. Therefore, the layout of the MOCAP system has been designed to guarantee both mandatory features.

Fig. 2 depicts adopted layout which permits to obtain a horizontal acquisition path of 7 meters and the area with internal oblique lines defines the zone in which the light marker can be moved in order to be detected by all Kinect devices during calibration phase.

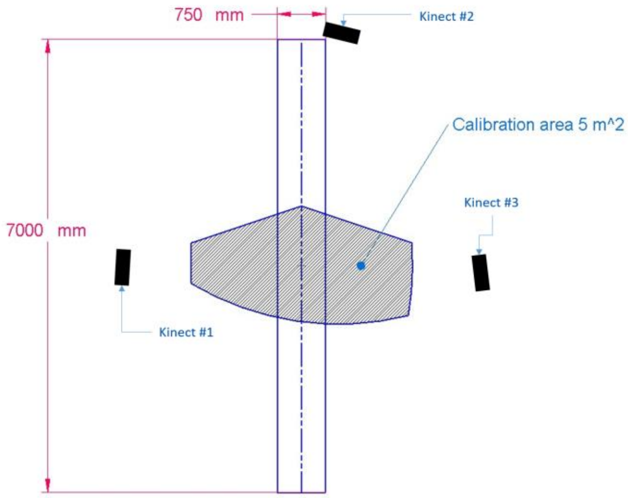


Fig. 2: Layout of the MOCAP system and calibration area.

Developed application

The developed application allows medical personnel to get information by starting from cinematic data extrapolated by iPiSoft MOCAP studio. Furthermore, the software embeds a set of medical rules, which permit to make available information according to patient data and measurements relative to the wheelchair setting. The application requires as input the following data and information:

- Two CSV files are exported from iPiSoft MOCAP Studio that contains cinematic data relative to SCI patients during wheelchair's pushing. A file contains information relative to virtual skeleton and its motion according to absolute coordinate system of 3D environment of iPi Mocap Studio. The other file contains cinematic information and motion data for each virtual bone of virtual skeleton according to its parent joint.
- Patient's data. In addition to personal information (i.e., name, surname, age and gender), the level on injury is asked to each patient [8]. Furthermore, the diameter of wheel of the wheelchair is required to allow pushing analysis.

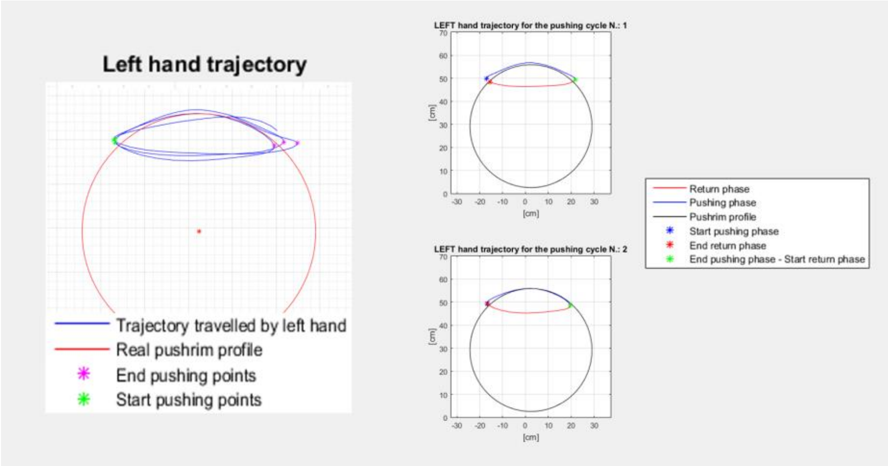
By using input data, the developed application computes and makes available the following information for medical assessment:

- Phases of each pushing cycle. The recorded motion of patient with wheelchair is analyzed in order to automatically detect all pushing cycles (Fig. 3.(a).) and its main phases which are pushing phase and return phase along both left and right wheels of wheelchair (Fig. 3.(b).).
- Angles of the upper limb. By following medical knowledge, a set of angles is computed to assess both maximum and minimal extension of arm during each pushing phase as well as postures and angles of chest and hip during whole acquired path (Fig. 4.).

The user interface of the application has been designed as a medical record, which can be exploit it as a further tool to improve the monitoring of the rehabilitation path. All data and graphics may be exported in PDF file format for sharing information with other physicians.

Clinical Tests:

The presented solution has been designed and developed in collaboration with the Rehabilitation center of the Papa Giovanni XXIII Hospital, Bergamo. The MOCAP system and the application have been tested through the involvement of twenty SCI patients with different levels of injury. The involved testers are four females and sixteen males who are from twenty-five to seventy years old. The optimized layout of MOCAP system has been duplicated to rehabilitation gym of the Hospital and each step of workflow to acquire motion of SCI patients on wheelchair has been executed by us. The acquisition of twenty patients has been done in 16 hours. Motion and cinematic data have been computed by iPiSoft Mocap Studio and have been used as input file in the developed application.



a) (b)

Fig. 3: All pushing cycles in relation to the push rim profile (a). Pushing phases for each detected pushing cycle(b).

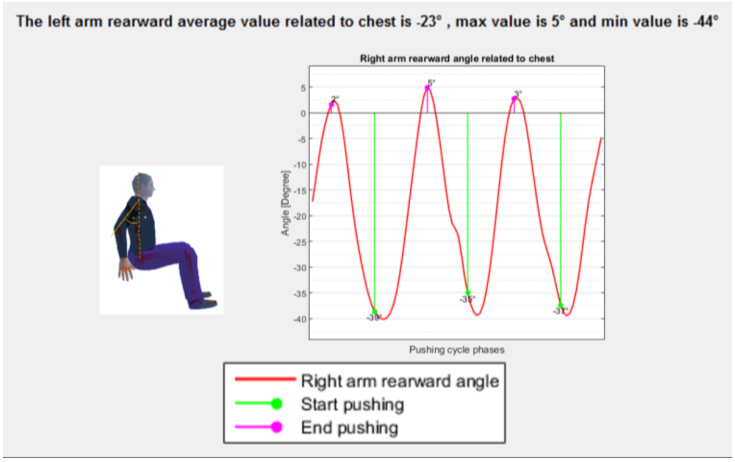


Fig. 4: Right arm rearward angle in relation to pushing cycles of wheelchair.

The obtained data have been evaluated very useful and congruent with medical assessment on each patient by involved medical staff. Detected issues relative to pushing phase of some patients have been directly evaluated by medical personnel after the use of designed solutions and these defects have been effectively confirmed. In particular, the maximum angle obtained when arms achieve maximum rearward extension (Fig. 4.) has been the most important parameter for evaluating if the SCI patient executed pushing phase in the correct way. Kinect v2 sensors provided adequate measurements of hands, arms and shoulders movements, which are the key anatomical districts involved in the pushing cycles. The maximum error of 2 cm has been detected for the body districts occluded by wheelchair during the acquisition, such as the lower back. The acquisition of the other interested districts is affected by an error of 7-9 mm that could be relevant for a single frame, but it is negligible for the overall medical assessment. The analysis of pushing cycles is totally computed by means of the developed application starting from motion data of the body shape of patient. Therefore, proposed solution can be considered a good tool to help medical personnel during assessment of rehabilitation process for SCI patients. The current approach will be applied also for other type of rehabilitation exercise due to other type of injuries in which the rehabilitation process is needed, such as lower limb amputations, prosthesis at shoulder and hip, rehabilitation after surgery. Technological improvements may be done for further improvements of the presented solutions, new medical rules can be added in order to make the application more complete and useful. This can be done by using advanced artificial intelligence inside the developed application. MOCAP system can be improved by using tracking devices with a higher frame rate. In some acquisition of SCI patient, Microsoft Kinect device has a frame rate too low to obtain motion data useful enough to correctly evaluate pushing cycles of the wheelchair's pushing.

Conclusion:

The paper describes an innovative procedure based on the use of low cost MOCAP systems and an ad-hoc developed knowledge guided application, which helps medical personnel to objectively assess the rehabilitation paths of SCI patients. The designed solution has been developed in collaboration with medical personnel of rehabilitation center of Bergamo, who made available medical knowledge for creating rules that have been embedded in developed application. The system has been tested with several SCI patients and the medical feedback has been considered satisfied. New tests have been planned in order to try the application on a bigger number of SCI patients in order to understand how to improve the development of our solution.

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