Can low-cost motion capture systems be used to measure accurately joint reactions in powered-exoskeleton users?

Matteo Lancini[a*], Alberto Fornaser[b], Simone Pasinetti[a], Mariolino De Cecco[b], Giovanna Sansoni[a]

[a] *University of Brescia, BRESCIA, Italy*
[b] *University of Trento, TRENTO, Italy*

**Corresponding author: Matteo Lancini; matteo.lancini@unibs.it*

Abstract The purpose of this study was to investigate if a low-cost marker-less motion capture system, coupled with low-cost force sensors, could be used to accurately assess joint reactions during assisted gait. The case of powered-exoskeleton users who lost their locomotion due to Spinal Cord Injury (SCI) is of interest because (i) shoulder joint reactions are difficult to assess by therapists with visual inspection, but are critical factors to avoid secondary health issues, (ii) exoskeletons induce unexpected visual occlusions and shape deformation with respect to standard motion capture protocols, (iii) SCI subjects wearing powered exoskeletons still need to use crutches, but for balance only, with load patterns scarcely studied in the literature.
One expert user of a Rewalk© P5 model was asked to test a pair of instrumented crutches with force sensing capabilities, inside a gait lab monitored by a reference motion capture system and a low-cost system composed of time-of-flight cameras. Two set of inverse dynamic analyses were performed to assess joint reactions: one using kinematic data from the reference MoCap and one using kinematic data assessed with the low-cost setup. The root mean square (RMS) error for shoulder joint reactions assessed starting from the low-cost measurement ranged from 0.4% (longitudinal) to 1.1% (vertical) of the body weight.

Keywords Exoskeletons, motion capture, measurement, joint reactions

Introduction

Powered exoskeletons are an effective tool for paraplegic subjects to regain standing and walking ability, improving life quality and preventing secondary health complication (Federici 2015). To learn how to control the robot, however, the user needs several training sessions (Platz 2016) under the guidance of specialized physiotherapists.

Only a few of these clinical facilities are equipped with gait labs and even in those were motion capture (MoCap) is available, its usage is limited, because of the time needed for test setup and data analysis. As a result, therapists usually rely on their visual inspection to assess the upper limbs involvement in the assisted gait. This is particularly difficult because in powered exoskeletons pilots crutches are used for balance only, with load patterns scarcely studied in the literature. This makes overloading the shoulders due to an incorrect usage more likely, with adverse effects on the subject (Alm 2008).

A measurement system based on force-sensing crutches and standard marker-based motion capture is already available (Lancini 2016), but costs associated with traditional MoCap still make the solution unpractical in clinical settings not used for research purposes.

A cheaper solution has been explored replacing the traditional marker-based MoCap with low-cost time-of-flight cameras (MS Kinect v2), making the system marker-less, cheaper and easier to setup.

While the accuracy in terms of kinematics has been already studied in able-bodied (Mueller 2017), the exoskeleton worn by the subject makes induce unexpected visual occlusions and shape deformation with respect to standard motion capture protocols. The paper describes a preliminary test performed to assess how accurate is the estimation of the internal joint reactions made using this solution.

Methods

One expert user of a Rewalk P5 model suffering from paraplegia (T12 complete) was asked to walk in straight line in a gait lab equipped with a force platform. The subject was given a custom-made low-cost set of wireless instrumented crutches able to measure the ground reaction forces. A marker-less motion system, composed of 4 Kinect v2 units, was deployed in the room. A marker-based motion capture was used as *ground truth*, having a position accuracy of 0.1mm. The experimental setup is visible in Figure 1.

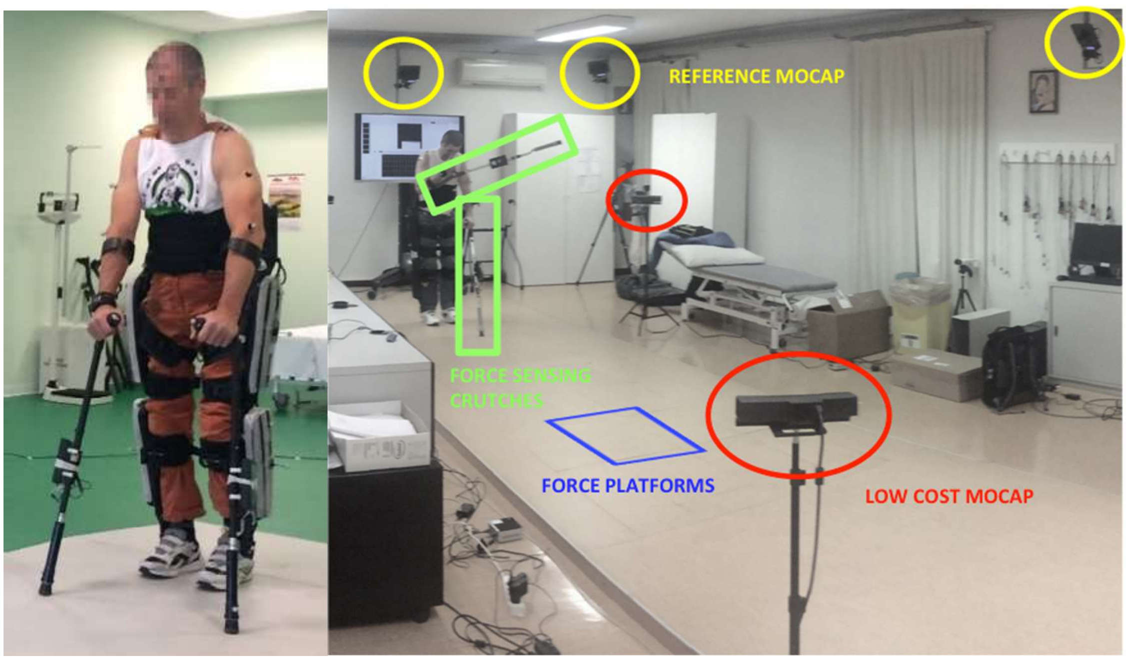

Figure 1. Left: the test subject wearing the exoskeleton, markers for reference MoCap and the instrumented crutches. Right: the test setup inside the gait lab. The force platforms, the force sensing crutches and both the reference and the low-cost MoCap systems are highlighted.

A numerical model of the subject, previously validated, was implemented in Opensim. 21 tests were repeated in the same conditions. Kinematics and dynamics results were computed with both the marker-less and the reference system as input data.

Results

The root mean square (RMS) error for upper limbs kinematics ranged from 5 deg (right arm adduction) to 20 deg (right elbow flexion), except for rotations around the body axis, which reached 110 deg (left arm rotation). The RMS error for shoulder joint reactions ranged from 0.4% (longitudinal) to 1.1% (vertical) of the body weight. Table 1 details the RMS errors for internal joint reactions in the shoulder and elbow joints.

Table 1. Internal Joint Reactions RMS error for upper limbs, expressed as fraction of the body weight. All tests were used.

Internal Joint Reactions (% BW)	Shoulder			Elbow		
	Longitudinal	Vertical	Lateral	Longitudinal	Vertical	Lateral
Right side	0.4%	1.1%	0.8%	0.8%	1.5%	0.4%
Left side	0.9%	0.9%	0.7%	0.5%	1.0%	0.4%

Conclusion and discussion

The high errors in kinematic measurement results seem to hint that pose could not be estimated accurately with this system. The low errors on the internal joint reactions apparently contradict this, presenting the measurement system as accurate. This apparent contradiction can however be explained by considering the measuring technology of Kinect sensors: time-of-flight cameras.

Unlike marker- or imu- based MoCap system, time-of-flight cameras provide information on surfaces only, without link to anatomical points: this makes the rotation of body segments with axial symmetry (legs, arms) difficult to assess due to ambiguity, but this rotation is not affecting the reaction force because it leads to an equivalent mechanical configuration.

While the system is unable to provide accurately the kinematics parameters, the global angles between the body segments are measured correctly and the assessment of the joint reactions is not affected, showing good accuracy. This could make measuring subjects while training feasible.

References

Federici S et al. (2015) *The effectiveness of powered, active lower limb exoskeletons in neurorehabilitation: a systematic review.* Neurorehabilitation 37(3):321-340

Platz T et al (2016) *Device-training for individuals with spinal-cord injury using a powered exoskeleton for technically assisted mobility: achievements and user satisfaction.* BioMed research international

Alm M, Saraste H, Norrbrink C (2008) *Shoulder pain in persons with thoracic spinal cord injury: prevalence and characteristics.* Journal of rehabilitation medicine 40(4):277-283

Lancini M et al. (2016) *Healthcare sensor system exploiting instrumented crutches fro force measurement during assisted gait of exoskeleton users.* IEEE Sensors, 16(23):8228-8237

Muller B et al. (2017) *Validation of enhanced kinect sensor based motion capturing for gait assessment*. PloS one 12(4):e0175813