Title:

Rgb-D Based Motion Capture and Data Analysis of Prosthetic Patients' Gait

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Introduction:

The use of sensors and measurement devices for medical purpose is creating new opportunities for both hospital and home applications. Some devices for monitoring or prevention, for instance for blood glucose, blood pressure or oxygen saturation measures, are already mature and widespread. On the other hand, medical sensors are not diffused for other purposes, such as for orthopedic evaluation of patient's motion or walking capabilities. This kind of measurement implies a complex evaluation of a number of interlinked parameters that, nowadays, are generally left to the personal skill and experience of the physician.

Introducing a robust and standard method for acquiring and elaborating motion data could bring to a number of benefits among which the shift from qualitative to quantitative result of gait analysis, the possibility to store and compare data over time and to link them to treatment and prosthesis characteristics.

The paper focuses on the way low cost Motion Capture (Mocap) techniques can be adopted to automatically analyze gait features of patients having a lower limb prosthesis. After showing the way Mocap is performed, the paper presents the results obtained with a real patient acquired while walking with a passive and with an active prosthetic knee.

Gait acquisition procedure:

In previous works [8], our research group developed a standard procedure to acquire motion data using RGB-D cameras. Video-gaming industry makes available on the market low cost technologies that are able to track human motion and export data usable in different domains. For these reasons, we chose MS Kinect [5] in the second version that is an optical device including a 1080p resolution camera and a depth sensor based on time of flight operating principle. It allows to acquire the point cloud of the scene during all time of recording. Our choice is justified by the study we previously executed [2] and in which we compared the first and the second generation of MS Kinect. We configured the scene with two Kinect v2 to have a complete 3D depth map of the environment and of the actor. This system has a heavy computational weight and for the reason each MS Kinect v2 has to be connected to a dedicated high-performance machine and then interfaced in a network. The disposition used for the acquisition phase is illustrated in Figure 1, in which we can see distances adopted between the two-faced devices. In the central area, we designed a walking area of 75x400 cm in which all acquisition are performed.

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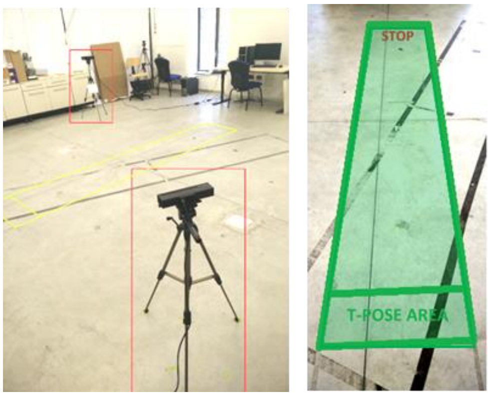

Fig. 1: Layout of motion capture scene.

This layout of the motion capture scene is required by the software used. Actually, iPiSoft's suite [4] is used to manage acquisition and data elaboration respectively with iPi Recorder and iPi Mocap Studio. In particular, this second software solution allows associating a virtual human model to the acquired point cloud of a human shape. The humanoid could be automatically scaled by the height and the gender of the subject to adapt it to the real shape, but it can be also edited manually to compensate some character's features (asymmetry, proportion and bones length). iPiSoft human model has 27 joints, as showed in the Figure 2.

In the first frame, the actor is in T-Pose and in the dedicated area, that is the standard position with legs straight and arms horizontally extended at shoulder height. The tracking function automatically matches the point cloud and the human model in each frame of the recording. Once this process is finished, the jitter removal tool cleans up data and prepares them for the exportation. The standard intensity adopted for the jitter removal is medium because the objective of this function is to reduce the peaks and to stabilize the output signal without modify his nature. The last step is to re-center the coordinate system on the projection point of body center of mass on the floor. iPiSoft's add-on BioMech is the tool used for the data export. For each video managed, the standard export formats of data files are .xlsx, .mat and .bvh. Matlab and Excel files contain the same data, which are position, velocity, acceleration, angles, angular velocity and angular acceleration in three dimensions for every joint. BVH file is the animation of the skeleton motion recorded in the scene. During the data export, we chose the absolute reference coordinates system for angles and positions. This means that each angle and each position refers to the 3D reference system placed in the first frame floor center.

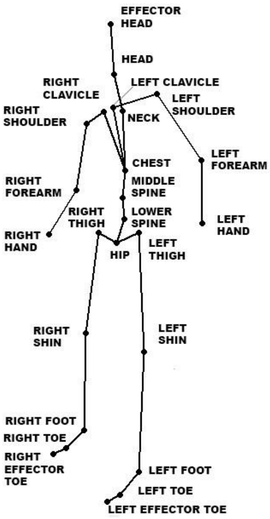

Fig. 2 : Reference skeleton with joints names.

Gait abnormalities automatic identification:

Literature does not converge to a unique classification of human gait abnormalities, but for lower limb amputee we consider the classification illustrated in ‘Atlas of Limb Prosthetics’ [1] in which all gait defects are identified and defined. Following this categorization, we developed a Matlab tool that execute the automatic identification of them, starting from an input file exported from iPiSoft.

Step analysis

In the first part of the code, data input have to be subdivided in each step phase. For this aim, the analysis of the three joints of the foot (foot, toe and effector toe) and in particular, their height from the ground makes possible to identify each step on both left and right side of the body. We identify also the durations of swing and stance phase of each step. The code also provides the percent variation between left and right steps duration and length.

Abnormalities identification

In this section there is the core of the application. Starting from the hypothesis that all defects are found only on one side of the body, we compared the behavior of interested joints on the two sides to identify every abnormality. For each defect identified we provide a value that explain its entity, classifying into three levels of severity.

Manual data management

In the last section of the code, we provide the possibility to consult all data referred to each joint such as positions and angles along all three axes. Plotting function is enabled to visualize data during time and to overlap results of left and right side. Excursion tool allows to insert the first and the last frame among which calculate the excursion of angle values that is useful to evaluate motion.

All results of the analysis are provided in a simple table in which we can find step data (duration, length…) and identified gait abnormalities with a few simple and useful parameters that immediately underline the defect.

Transfemoral patient gait analysis:

In this research work, we applied this method to a transfemoral patient with a prosthesis on the left leg. The patient is a 50 years old man. We executed tests with two different kinds of prostheses (Figure 3): the first one is an artificial leg with a monocentric Ottobock 3R45 passive knee [7] and the other one is an electronic Ossur Rheo active knee [6].

Fig. 3 : a) Ottobock 3R45 hydraulic knee b) Ossur Rheo 3 knee.

We executed three motion acquisitions for each type of prosthesis. The patient during all tests walked in the designed area with a normal gait, step frequency and velocity. For each recording we acquired 5-6 steps on average, the Matlab tool is based on the analysis of two steps that are isolated in a previous

phase. This action allows avoiding the starting and the stopping steps that are a particular condition in which there a transaction phase of acceleration or deceleration.
In Table 1, we show the resulted gait abnormalities according to prosthesis type.

Abnormalities	3R45		RHEO KNEE	
	Right	Left (pros)	Right	Left (pros)
Lateral trunk bending	High		Medium	
Wide walking base	-	-	-	-
Circumduction	-	-	Low	-
Medial/lateral torsion	-	-	-	-
Foot rotation at the contact	-	-	-	-
Jumped walk	-	-	-	-
Asymmetrical gait	-	-	-	-
Insuf/exces toe raising	Low insuf		Low insuf	
No plantarflexion	-	Low	-	Low
Speedy plantiflexion	-	-	-	-
Lordosis	-	-	-	-

Tab. 1: Gait abnormalities resulted on the same patient with different knees

Analyzing data acquired, we can say that the most relevant gait abnormality, according to the Atlas of Limb Prosthetics, is the “lateral trunk bending” that in some cases is over the threshold level of severity. The parameter referred to this movement is the rotation around the frontal axis of the lower spine link. The amputee leans toward the amputated side of more than ten degrees when the prosthesis is in the stance phase. Apparently, this is not a high rotation value, but since the center of rotation is positioned in the lower back, the lateral shift of the upper trunk can be up to 10 cm, and this imply a critical bending.

We noted also two other repeated abnormalities that are “no plantarflexion” and “insufficient toe raising”. The first one is connected to the rigidity of the prosthetic foot that do not reproduce properly the ankle articulation. The second one is referred to a non-homogenous distance between ground level and foot toe on the two sides of the body. Both these defects have low level of severity.

There is also an acquisition in which we can identify a minimum “vaulting” problem that means the patient executed a jumped gait varying the distance between ground and the top head point.

We executed three gait tests with the same patient, in the same day and in the same environment. The two prosthetic legs are exactly the same, including the socket, except for the knee. We expected that the electronic active knee could improve some gait issues compared to hydraulic passive one. Surely, the outcomes confirm that there is a benefit, but some abnormalities still affect the gait. In particular, the major improvement is the reduction of lateral trunk bending that is the most serious defect found causing muscle-skeletal disease [3]. The absence of plantarflexion is due to prosthetic foot that is the same in both artificial legs.

Discussion:

Human gait surely is a distinctive feature of a single human being. Each one has a specific gait that allow for example to recognize a subject at a distance without seeing the face but seriously considering walking [11]. If macroscopically a gait is recognizable, it is not the same from the point of view of a singular step. In fact, each step is different and gait parameters vary very quickly, despite the walking analysis give the same results. In this way, repeatability of a gait phase is difficult and for this reason, also data analysis results to be complicated. The analysis tool developed addresses this problem working on average values, but there are global aspects we cannot estimate with the Mocap. For instance, working with transfemoral amputee patients two important aspects that influence the repeatability of gait analysis are the fatigue and the diligence used during gait acquisition. On one hand, actually, the patient will be prone to perform a better gait when s/he knows the acquisition is running. On the other hand, walking in different moment during the day or in a moment in which the patient is particularly tired can affect the performance.

The analysis carried out highlight sharply the real problems affecting the patient which are the same of those identified with the traditional observation of an orthopedic physician. Anyway, the diagnosis made by a medical staff is not going to be replaced because only a human expert can make a critical assessment of a walk. The aim reached with this work is to offer a robust tool, able to provide the medical staff with an objective and measurable evaluation of a gait, useful to validate the optical and manual analysis. In the case of amputee patients the developed tool is able to identify and quantify the abnormalities affecting a patient's gait. In particular, a comparison among two dataset related to different prosthesis configuration and different knees has been performed. The comparison has a dual meaning: from a methodology point of view it allows assessing the performance of the entire process and in particular the repeatability of gait measures; from a data point of view it constitutes an example of the way measures performed in two different moment, or with different prosthesis, can be easily managed by the operator to derive a trend of evolution.

Conclusions:

Gait analysis belongs to a research field in which it is not possible to sharply define an optimum, i.e. the standard correct gait that in some research works is defined as a statistical average [9-10]. Parameters and features to evaluate a gait are not unique and for all these reasons it is not easy to define what is not correct or abnormal. In this work, we proposed a method in which we compare the average of values on right and left side of body to understand if there are defects, starting from joints positions and angles. This procedure show good reliability but it also causes some ambiguities in the identification of the side on which the defect is visible. Moreover, there is also a large set of parameters that need to be defined by the user before starting to analyse data. Their values come from the experience of medical staff and from literature, while they would rather be patient-based. By the way, a broad application of quantitative analysis of motion by means of Mocap tools will allow partially overcoming these issues, for instance, by creating well defined reference archetypes.

References:

[1] Berger, N.: Analysis of Amputee Gait, Atlas of Limb Prosthetics, Part III: The Lower Limb, Chapter 14, Digital Resource Foundation for the Orthotics & Prosthetic Community. Available at http://www.oandplibrary.org/alp/chap14-01.asp

[2] Comotti, C.; Massa, F.; Regazzoni, D.; Rizzi, C.: Towards automatic gait assessment by means of rgb-d mocap, ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2015, Boston, Massachusetts, USA, 2015.

[3] Farahpour, N.; Younesian, H.; Bahrpeyma, F.: Electromyographic activity of erector spinae and external oblique muscles during trunk lateral bending and axial rotation in patients with adolescent idiopathic scoliosis and healthy subjects, Clinical Biomechanics, 30(5), 2015, 411-417. http://dx.doi.org/10.1016/j.clinbiomech.2015.03.018.

[4] iPiSoft: http://ipisoft.com/.

[5] Microsoft Kinect: https://dev.windows.com/en-us/kinect.

[6] Ossur Rheo Knee 3: http://www.ossur.com/prosthetic-solutions/products/knees-and-legs/bionic-knees/rheo-knee-3.

[7] Ottobock 3R45 knee: http://www.ottobock.it/soluzioni-protesiche/arto-inferiore/.

[8] Regazzoni, D.; Rizzi, C.: Patients' Evaluation Based on Digital Motion Acquisition, Proc. CAD'15, London, UK, 2015, 143-147. http://dx.doi.org/10.14733/cadconfP.2015.143-147

[9] Schutte, L. M.; Narayanan, U.; Stout, J.L.; Selber, P.; Gage, J.R.; Schwartz, M.H.: An Index For Quantifying Deviations From Normal Gait, Gait & Posture, 11(1), 2000, 25-31. PMID: 10664482

[10] Schwartz, M. H.; Rozumalski, A.: The Gait Deviation Index: A New Comprehensive Index Of Gait Pathology, Gait & Posture, 28(3), 2008, 351-357. http://dx.doi.org/10.1016/j.gaitpost.2008.05.001.

[11] Spinello, L.; Arras, K.O.: People detection in RGB-D data, IEEE/RSJ International Conference on Intelligent Robots and Systems, 2011, 3838-3843. http://dx.doi.org/10.1109/iros.2011.6095074