Influence of different body pose reconstruction methods in the solution of the inverse dynamic problem during human gait without force plates

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The inverse dynamics is a classic problem to be solved in gait analysis. The conventional use of inverse dynamics involves the estimation of joint forces and moments based on kinematic data, anthropometric parameters and force plate data. The procedure uses the measured ground reactions and, beginning with those segments in contact with the ground, calculates joint forces and moments at each successive segment. However, as force plate data only gives the ground forces and moments resultants, the model of the foot must be necessarily monosegment. Gait models based only on kinematics can be used for studies of multisegmented feet. They could be also used outside the laboratory where force plates are not available. In the double-support phase of gait, the ground reaction forces include twelve unknowns, what makes the inverse dynamics problem indeterminate. To solve the indeterminancy the Smooth Transition Assumption (STA) proposed by Ren et al.[1] is used. This algorithm is based on the assumption that the reaction forces and moments at the trailing foot decay according to a certain law which combines exponential and linear functions, reducing the number of unknowns to six. In this work ground reaction force and moments calculated using different body pose reconstruction methods were compared to data provided by force plates in case of a monosegment foot model. The results were compared to analyze the goodness of the inverse dynamics based only on kinematics.

An experiment has been designed to obtain quantitative data of normal walking. Gait analysis was carried out on one adult male subject with no pathologies in gait using a modified Newington gait model (MoPiG) [2] as set of markers used to defined the position and orientation of the different parts of the human body. The marker trajectories were measured at 100 Hz using a Vicon six-camera motion capture system. Ground reaction forces were recorded with two AMTI force plates and a sample frequency of 1000 Hz.

Two different body pose reconstruction methods have been implemented to define the position and orientation of the different segments of the human body during gait through the position of the markers attached to the skin.

The first method is named UNO for un-optimized and is based on the Newington-Helen Hayes gait model [3]. It calculates biomechanical segment lengths (distance between the joint centers) from the static trial. Rigid segments are defined frame-by-frame. Each segment is defined by an origin (generally located at the proximal joint center) along with three orthogonal axes which are defined at every frame from the external markers. This method yields dislocations and residuals, since the constant length segment does not coincide in every frame with the distance between the joints centers, as the local position of the markers does not coincide either with those obtained in the static trial, mainly due to soft tissue artefacts. It is important to highlight that the position obtained by means of the markers set with UNO is completely independent of the way the joints are modelled.

In GOM procedure[4] the goal is to minimize the differences between the position of the markers experimentally obtained and the position of the markers defined by the biomechanical model. The optimization process of the residuals is performed simultaneously in all segments subject to kinematic constraints. Model-determined marker positions correspond to the positions of the markers estimated under the assumption that they were rigidly attached to the corresponding segment of the model.

The mechanical model is composed of two feet, two shanks, two thighs, one pelvis, one trunk, one head, two upper-arms, two forearms and two hands. As fifteen bodies are considered the total number of coordinates is ninety. The masses, the center of mass locations and the moment of inertia tensors were obtained from the literature and scaled to the subject of this study using a linear method. The procedure is detailed in [5]. A static trial was recorded and processed to define the local reference frames of the segments, their lengths and the joint positions for the both body pose reconstruction procedures. Regarding the kinematic joint constraints the model considers that all joints in the biomechanical model behave as spherical joints and therefore, the number of degrees of freedom is 48.

The motion of a multibody system is due to the forces and moments applied on it. This relation between the motion and the forces and moments is presented in Eq. (1) and was taken from the work of Nikravesh [6].

$$\mathbf{M}\ddot{\mathbf{y}} = \mathbf{f}^{\mathbf{ext}} + \mathbf{h} + \mathbf{f}^{\mathbf{reac}} \tag{1}$$

Where $\ddot{\mathbf{y}}$ is the vector of accelerations, $\mathbf{M}$ is the mass matrix of the system. $\mathbf{f}^{\mathbf{ext}}$ is the vector of external generalized forces containing the gravity loads. $\mathbf{h}$ is the vector of quadratic terms on velocities. $\mathbf{f}^{\mathbf{reac}}$ is the vector of generalized reactions.

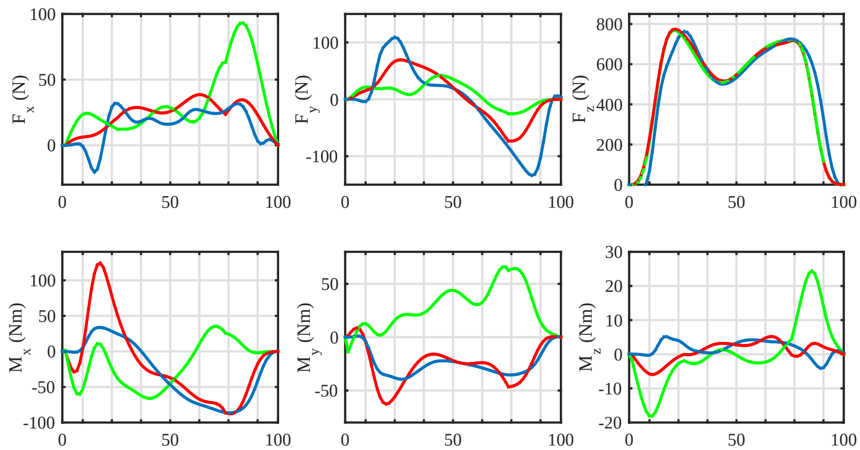

Fig. 1: Ground reaction forces and moments in global coordinates. X: lateral-medial direction. Y: anterior-posterior direction. Z: vertical direction. Moments referred to the center of the force plates. In blue, provided by the force plates. In red, obtained as the solution of the inverse dynamic problem using UNO. In green, obtained as the solution of the inverse dynamic problem using GOM

It can be observed in Fig. 1 that GOM method provided worse results than UNO. This result is obtained because the assumptions introduced in the body pose reconstruction method (no dislocations and spheric joints) may introduce an error bigger than main source of error due to the experimental procedure: the soft tissue artefacts. UNO procedure leaded to a good estimation of the ground reaction forces and moments in the whole gait cycle but the double support phases. Results could be improved in these phases using different transition functions. In inverse dynamics analysis, kinematic constraints are not essential but can accomplish different functions. First, they can serve to reduce the number of markers in the motion capture protocol, but only up to a certain point. It must be noted that the markers set is generally redundant to make the capture protocol more robust against failures in the data acquisition. Secondly, kinematic constraints can also help to define the driving moments to be used in the muscular dynamics. If no constraints were defined, it would not be possible to distinguish between driving and reaction moments. In these cases, more complex joint definitions should be used to improve multibody models.

References

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