Identifying humanoid and human physical parameters

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Abstract

Dynamical and kinematic analysis of humanoid and human movements require accurate estimation of segment mass parameters (mass, center of mass, and inertia matrix), and their misinterpretation can lead to significant variation in estimated joint kinematics. In the field of robotics, several methods have been developed for estimation of mass parameters of humanoid robots, as well as human subjects, based on linear properties of dynamic equation of bipedal systems with respect to the set of mass parameters. This talk will focus on those methods addressing the state-of-the-art research in the topic. Examples of both human and humanoid robots mass parameters estimation

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will be given. Identified mass parameters improve output of human dynamic analysis and humanoid simulation and model-based control.

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1. Introduction

Body segment inertia parameters (BSIPs) are important variables in biomechanical analyzes. In case of human inertia parameters are usually estimated using scaling equations provide in anthropometric tables based on data collected from young subjects [1]. Extrapolating those data to the different population or different age subjects is restrictive due to different body morphologies.

In case of humanoid robots, BSIPs given by robot manufacturers are estimated using CAD software. Those parameters are rough estimation of true inertia parameters and they often do not take into account wiring materials.

Hence, in this study we propose a method for estimation of subject specific whole body segment mass parameters. The method applies is based on use of Hierarchical Quadratic Programming (HQP) [2] optimization approach and linear properties of rigid bipedal body dynamics with respect to the BSIPs.

2. Method

The dynamic equations of dynamics of bipedal multi body systems is expressed by the following equation [3]:

$$\begin{bmatrix}H11 & H12\\ H21 & H22\end{bmatrix}\begin{bmatrix}\ddot{q}1\\ \ddot{q}2\end{bmatrix}+\begin{bmatrix}b1\\ b2\end{bmatrix}=\begin{bmatrix}0\\ \tau\end{bmatrix}+\sum_{k=1}^{Nc}\begin{bmatrix}J1k^{T}\\ J2k^{T}\end{bmatrix}fk \quad (1)$$

Where:

- q_1 represents position and orientation of base link, and q_2 is vector of joint angles of the body segments;
- H_{1j} and H_{2j} (j = 1,2) are the inertia matrix of the base link and body segments, respectively;
- vectors b_1 and b_2 are the bias force vectors including centrifugal, Coriolis, and gravity forces of the base link and body segments, respectively;
- τ is the vector of joint torques of the body segments;
- f_k is the vector of the external forces at contact k. N_c □is the number of contact points with the environment;
- J_1 and J_2 are Jacobian matrices at contact k that map external forces to the joint space of the base link and □body segments, respectively.□

From equation (1) the following equation of motions of base link can be written in its linear form with respect to the set of BSIPs [4]:

$$Y\varphi = F \quad (2)$$

where:

- Y is the regressor matrix which is a □function of q_1, q_2 and their derivatives;
- F is the vector of external forces applied to the link;
- φ is a vector of BSIPs to estimate.

For each body segment i, vector φ_i is composed of 10 □parameters:

- the mass of the segment m_i ;
- the Center of Mass (CoM) of the segment i;
- the components of the inertia matrix I_i expressed in the segment frame;

The equation (2) can be solved by formulating a four level optimization problem that we solve with an HQP solver [2]:

$$(l1 \le A1\varphi \le u1) \prec (l2 \le A2\varphi \le u2) \prec (Y\varphi = F) \prec (\varphi = \varphi^{ref}) \quad (3)$$

where vector φ^{ref} is a vector of BSIPs parameters found in Dumas Anthropometric Tables (AT) [5] in case of human BSIPs identification, or extracted from CAD date in case of humanoid robot BSIPs identification. The notation is taken from [2]. The first level inequality constraints is chosen to enforce the solution to be physically plausible. The second level inequality constraints is chosen to enforce symmetry between the BSIPs of the left side of the body.

3. Experimental validation

3.1. *Experiments with human subject*

Motions of one healthy adult volunteer (male, 70kg, 1.82m) were measured using a stereophotogrammetric system and force plates. The participant performed optimal motion defined in [4] that excites the dynamics of the considered system. In order to test the ability of the algorithm to detect segment mass changes, the participant was asked to perform validation trial executing the same motion and wearing a weighted belt located at the lower trunk level.

Joint angles were estimated from marker positions using Cortex Motion Analysis software.

3.2. *Experiments with humanoid robot*

The exciting trajectories [6] were executed into humanoid robot. Examples of exciting trajectories are shown in Fig. 1. The robot is 1.54m height, with the CAD mass of 56kg. It is composed of 31 segment links, and has 30 deegres of freedom. The robot is equipped with sensors measuring the joint angles, force sensors under the feet and hands, accelerometer and gyroscope sensors. Due to the maintenance of the robot some parts were replaced.

The robot modifications resulted in changes of its segment inertial properties.

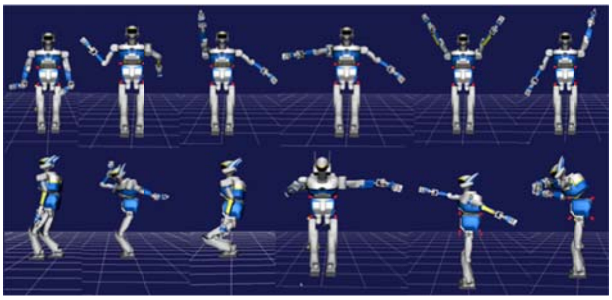

Fig. 1. Examples of exiting trajectories performed by humanoid robot.

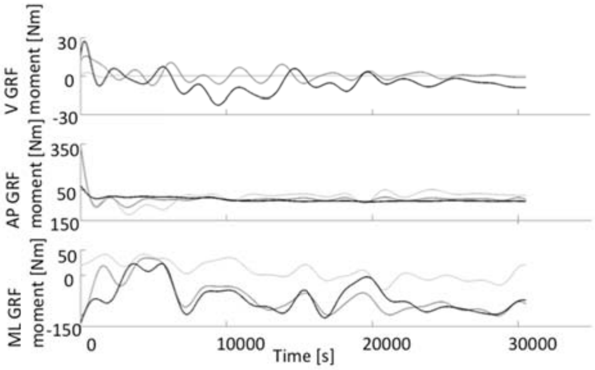

Fig. 2. GRF moments in vertical (V), anterior- posterior (AP), and medio-lateral (ML) directions reconstructed using identified BSIPs (dark gray line), BSIPs from AT (light gray line), obtained using forceplates measurements during the experiment with the human subject (black line).

4. Results

Example of Ground Reaction Force (GRF) moments reconstructed using proposed method, method based on use of AT, and those obtained using the force plates measurement during the experiment with human subject is shown in the Fig. 2. Figure 3 illustrates increase of identified segments masses of human subject model and those computed using AT based method during the validation trial when the volunteer was carrying weighted belt located at lower trunk level. The mass of each segment link of humanoid robot obtained using our method and the ones given by CAD software are presented in Fig. 4.

5. Conclusion

We presented a method, based on use of HQP optimization technique, for identification of segment inertia parameters. We compered results obtained using our method with the results obtained using BSIPs computed from Dumas AT [5] in case of human BSIPs identification and extracted form CAD data in case of identification of BSIPs of humanoid robot. The method proposed in this study showed better performances in estimation of the atypical asymmetric segment weights of human subject, and was able to estimate mass properties of modified segments of humanoid robot.

Moreover, the proposed method was able to reconstruct the ground reaction forces and respective force moments more accurately compared with methods based on use of anthropometric tables or CAD data.

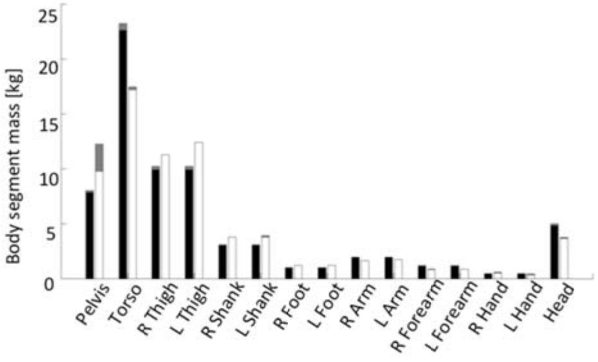

Fig. 3. Segment mass increase (gray) of identified body segment masses (white) and body segment masses from AT (black) for the human subject for validation trial. Right and left sides of the human body are abbreviated with R and L, respectively.

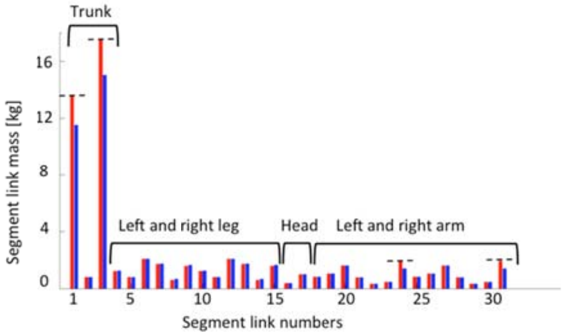

Fig. 4. Segments masses of humanoid robot identified using proposed method (red) and extracted from CAD data (blue). Dotted lines show expected segment mass based on the knowledge of replaced components.

Acknowledgements

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