

# Overview on dynamic identification methods of floating base anthropomorphic structures

Vincent Bonnet, Maxime Gautier, Raphaël Dumas, Samer Mohammed, Thomas Robert, Gentiane Venture, Philippe Fraisse

▶ **To cite this version:**

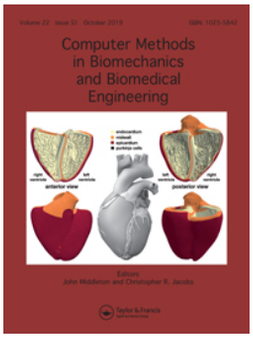
Vincent Bonnet, Maxime Gautier, Raphaël Dumas, Samer Mohammed, Thomas Robert, et al.. Overview on dynamic identification methods of floating base anthropomorphic structures. 44th Congress of the Société de Biomécanique, Oct 2019, Poitiers, France. pp.S471-S473, 10.1080/10255842.2020.1714985 . hal-03673695

**HAL Id: hal-03673695**
**https://hal.science/hal-03673695**

Submitted on 20 May 2022

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Taylor & Francis
Taylor & Francis Group

Computer Methods in Biomechanics and Biomedical Engineering

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/gcmb20

# Overview on dynamic identification methods of floating base anthropomorphic structures

V. Bonnet, M. Gautier, R. Dumas, S. Mohammed, T. Robert, G. Venture & P. Fraisse

**To cite this article:** V. Bonnet, M. Gautier, R. Dumas, S. Mohammed, T. Robert, G. Venture & P. Fraisse (2019) Overview on dynamic identification methods of floating base anthropomorphic structures, Computer Methods in Biomechanics and Biomedical Engineering, 22:sup1, S471-S473, DOI: 10.1080/10255842.2020.1714985

**To link to this article:** https://doi.org/10.1080/10255842.2020.1714985

© 2020 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

Published online: 22 May 2020.

Submit your article to this journal

Article views: 268

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=gcmb20

COMPUTER METHODS IN BIOMECHANICS AND BIOMEDICAL ENGINEERING
2019, VOL. 22, NO. S1, S471–S473
https://doi.org/10.1080/10255842.2020.1714985

Taylor & Francis
Taylor & Francis Group

OPEN ACCESS Check for updates

# Overview on dynamic identification methods of floating base anthropomorphic structures

V. Bonnet[a], M. Gautier[b], R. Dumas[c], S. Mohammed[a], T. Robert[c], G. Venture[d] and P. Fraisse[e]

[a]LISSI, Univ. of Paris-Est Créteil, Créteil, France; [b]LS2N, Nantes University, Nantes, France; [c]Univ. Claude Bernard Lyon 1, IFSTTAR, LBMC, Villeurbanne, France; [d]Dept. Mech. Sys. Eng, Tokyo Univ. of Agriculture and Technology, Tokyo, Japan; [e]LIRMM, Univ. Montpellier, Montpellier, France

## 1. Introduction

Body segment inertial parameters (BSIP) are of crucial importance when analyzing, assisting, or controlling anthropomorphic structures. The human body as well than humanoids and exoskeleton robots are highly nonlinear and redundant systems with specific subject/unit BSIP. A good knowledge of the BSIP is important when simulating an anthropomorphic system or when using model-based controllers to predict/control a dynamic behavior. Humanoids or exoskeletons BSIP are usually obtained from CAD data, but these do not take into account cabling, covers or embedded computers. In human, BSIP cannot be directly measured in a non-invasive way, they are classically estimated using anthropometric tables. However, these tables are usually not adapted to atypical population (children, elderly, obese, individual with prostheses, etc.). Anthropomorphic structures rely on floating base system's equations of motion. Floating base structure nature allows to use the external wrench at the base frame $\mathbf{F}_0$ to identify the so-called *base parameters*. The base parameters are linear regrouping relations between all the segment's mass, 3 D center of mass position and inertia matrix that are called in the literature the *Standard Parameters (SD)*. Base parameters, when identified using the external wrench, are not relevant to estimate variables of interest such as joint torques or for hard real-time application based on recursive Newton-Euler algorithm. Recovering the complete set of SP is a non-linear problem admitting an infinite number of solutions with some solutions that might not be physically consistent For example, masses may end up negative. In order to prevent such unfeasible solutions, different methods have been proposed in the literature. A weighted SVD decomposition (Gautier 2013) can be used to obtained BSIP but not in a strictly constrained fashion. More recently, constrained optimization processes have been proposed using QP in real-time or based on linear matrix inequalities framework (Wensing 2018). For human, whole-body stereophotogrammetric and kinetic data, measured by a force-plate, can be used to identify BSIP (Bonnet 2016). For robots, besides joint angles that are measured by joint encoders, multimodal kinetic data can be used. Joint torque sensors and motor current are sensors that carry most of the information but in case those are not available external wrench can be used. In the case of human-exoskeleton system both joint and base level kinetic information should be used. Nevertheless, as any identification process exciting motions are to be considered. To do so we proposed to use non-linear constraint optimization approach to handle mechanical constraints. The same framework can be used for human, humanoids and exoskeleton robots. This study aims at presenting and discussing perspectives for the different approaches proposed by our group over the last five years to evaluate BSIP of anthropomorphic structures.

## 2. Methods

### 2.1. Mechanical model

Geometric and kinematic models were obtained starting from a Modified Denavit-Hartenberg representation of the anthropomorphic structure assuming rigid bodies. Dimensions were estimated from markers placed on anatomical landmarks or CAD data. Initial BSIP of segments ($\boldsymbol{\phi}_{\mathbf{CAD}}$) were estimated from anthropometric tables or CAD data.

### 2.2. Identification model

The unactuated part of the system's dynamics can be written as (Ayusawa 2013): $\mathbf{R}\boldsymbol{\phi} = \mathbf{F}_0$, with: $\boldsymbol{\phi}$ the vector of BSIP; $\mathbf{R}$ the regressor matrix, function of the joint ($\boldsymbol{\theta}$, $\dot{\boldsymbol{\theta}}$, $\ddot{\boldsymbol{\theta}}$) and base ($\mathbf{q}_0$, $\dot{\mathbf{q}}_0$, $\ddot{\mathbf{q}}_0$) positions, velocities and accelerations. The regressor matrix is simply

© 2020 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

the factorized form of the dynamic model by the SP. Using the free software Symoro+ (Khalil 1997) it can be obtained symbolically for each time stamp:

$$\overline{\mathbf{R}}\boldsymbol{\phi} = \begin{bmatrix} \mathbf{Y}(1) \\ \vdots \\ \mathbf{Y}(\mathbf{n}) \end{bmatrix} \boldsymbol{\phi} = \begin{bmatrix} \mathbf{F}_0(1) \\ \vdots \\ \mathbf{F}_0(\mathbf{n}) \end{bmatrix} = \mathbf{F}_0 \qquad (1)$$

$\overline{\mathbf{R}}$ is not full rank, the system was further reduced to $\overline{\mathbf{R}}_\mathbf{b}\boldsymbol{\phi}_\mathbf{b} = \mathbf{F}_0$, where $\boldsymbol{\phi}_\mathbf{b} = \mathbf{L}\boldsymbol{\phi}$ are linear combinations of $\boldsymbol{\phi}$. It was then solved using a Moore-Penrose pseudo inverse: $\boldsymbol{\phi}_\mathbf{b}{}^* = \mathbf{R}_\mathbf{b}{}^+\mathbf{F}$. For a human wearing and exoskeleton two subsystems should be considered. This leads to two regressor matrices $\overline{\mathbf{R}}_\mathbf{b} = \begin{bmatrix} \overline{\mathbf{R}}_{\mathbf{bE}} & 0 \\ 0 & \overline{\mathbf{R}}_{\mathbf{bH}} \end{bmatrix}$ (2), with $\overline{\mathbf{R}}_{\mathbf{bE}}$ the regressor matrix corresponding to the exoskeleton and $\overline{\mathbf{R}}_{\mathbf{bH}}$ the regressor matrix corresponding to the human. Moreover, the dynamometric data input vector $\mathbf{F}_0$ should be composed of the external wrench and of the exoskeleton measured joint torques.

## 3. Results and discussion

Identified SP vector ($\boldsymbol{\phi}_{ID}$) was estimated by solving the following QP problem (Jovic 2016):

$$\min_{\boldsymbol{\phi}_{\mathrm{ID}}} ||\boldsymbol{\phi}_{\mathbf{CAD}} - \boldsymbol{\phi}_{\mathbf{ID}}||^2 + \alpha\left|\left|\mathbf{W}\left(\mathbf{L}\boldsymbol{\phi}_{\mathbf{ID}} - \boldsymbol{\phi}_\mathbf{b}^*\right)\right|\right|^2 \qquad (3)$$

$$\text{s.t. } \mathrm{M_i} > 0;\ \ CoM^- \leq \mathrm{CoM} \leq CoM^+;\ \ \mathbf{v}^T\mathbf{I}\mathbf{v}; \boldsymbol{\phi}_\mathbf{b}^* = \mathbf{L}\boldsymbol{\phi}$$

In order to ensure physical consistency a constraint stating that the all masses must be positive was included. Additionally, the CoM position of each link was constrained to be inside a segment's specific oriented bounding box. The inertia matrices $\mathbf{I}$ were constrained to be positive define, i.e., for every non-zero vector $v \in \mathbb{R}^3$, $\mathrm{v}^T\mathrm{Iv} > 0$.

### 2.3. Generation of exciting motions

Moving an anthropomorphic structure requires solving numerous constraints as it is usually composed of more than twenty DoFs with limited actuation capabilities, is intrinsically unstable, and is prone to auto-collisions. Identifying BSIP requires hundreds of samples per trajectory for each joint. Generating exciting motions for such system is not trivial. The large problem size often leads to unfeasible solutions. We propose to decouple the excitation of static parameters (masses, CoMs) and of dynamic parameters (inertias). This can be easily done by using base parameters sub-matrices that are composing $\overline{\mathbf{R}}_\mathbf{b} = \begin{bmatrix} \overline{\mathbf{R}}_{\mathbf{bM}} & \overline{\mathbf{R}}_{\mathbf{bCoM}} & \overline{\mathbf{R}}_{\mathbf{bI}} \end{bmatrix}$ with $\overline{\mathbf{R}}_{\mathbf{bM}}$, $\overline{\mathbf{R}}_{\mathbf{bCoM}}$ and $\overline{\mathbf{R}}_{\mathbf{bI}}$ being the sub-regressors matrices that correspond to the mass, center of mass and inertia base parameters. Doing so, we can find the exciting joint trajectories $\mathbf{q}_\mathrm{E}$ that excite the BSIP by minimising the condition number of the sub-regressor matrices: $\min_{\mathbf{q}_\mathrm{E}} cond(\overline{\mathbf{R}}_\mathbf{b})$ under the constrains that joint mechanical limitations, balance and auto-collisions are respected.

Once generated $\mathbf{q}_\mathrm{E}$ were reproduced as best as possible by the subject/robot while standing/being hanged on/to a force-plate and kinematic recorded.

## 3. Results and discussion

The proposed framework has been tested with numerous (>20) human subjects starting from 3 degrees-of-freedom planar model to whole body model. Overall reconstructed external wrenches were always in correct agreement with the experimental values even during cross validation results. This is expected because external wrenches were used to feed the identification process. The validation of BSIP was done by performing the identification process when the subject/robot carries an additional known mass. The accuracy that was found was in average of 0.5 kg. Regarding the joint torque estimates significant differences were observed when comparing to the ones obtained when using anthropometric tables data. However, in human there is no reference data to be compared to. Future work will consist in using joint torque sensors from new generation humanoid robot to further validate our approach. Several exoskeleton robots, that are not conceived to fully support the wearer, cannot support their own weight or do not have actuated ankle joint. Consequently, to identify their BSIP it is necessary either to hang them up to a fix force sensor or to perform the identification when the human wears the exoskeleton. Recently we have chosen the second solution and showed that using (2) and a two-step identification process it is possible to isolate the exoskeleton parameters. However, (3) because it is an hybrid cost function is relatively sensitive to the quality of the external wrench fitting. An incorrect tuning of $\alpha$ can lead to unrealistic parameters. This is specially the case for very small and thus un-influential BSIP. To detect the un-influential BSIP we have proposed a simple criterion based on the ordered cumulative sum of the colons of the regressor matrix. Doing so it is possible to exclude form the identification process all the BSIP that do not contribute to the 95% of the whole dynamics. In case of human walking, it means that 76 out of 150 BSIP, i.e., most of the inertias can be ignored. A future step will be to perform an actual

validation of these estimated BSIP using a known object (e.g., prosthesis).

## 4. Conclusions

The proposed framework for anthropomorphic structure BSIP identification provides encouraging results showing that relevant segmental BSIP can be obtained using identification techniques and a normalized and optimal exciting motion procedure.

## References

Ayusawa K, Venture G, Nakamura Y. 2014. Identifiability and identification of inertial parameters using the underactuated base-link dynamics for legged multibody systems. Int J Robot Res. 33(3):446–468.

Bonnet V, Fraisse P, Crosnier A, Gautier M, Gonzalez A, Venture G. 2016. Optimal exciting dance for identifying inertial parameters of an anthropomorphic structure. IEEE Trans Robot. 32(4):823–836.

Gautier M, et al. 2013 identification of consistent standard dynamic parameters of industrial robots. IEEE Int. Conf. Advanced Intelligent Mechatronics.

Jovic J, Escande A, Ayusawa K, Yoshida E, Kheddar A, Venture G. 2016. Humanoid and human inertia parameter identification using hierarchical optimization. IEEE Trans Robot. 32(3):726–735.

Khalil W, Creusot D. 1997. SYMORO+: A system for the symbolic modeling of robots. Robotica. 15(2):153–161.

Wensing P, et al. 2017. Observability in inertial parameter identification. arXiv:1711.03.

**KEYWORDS** Identification; body segment inertia parameters

vincent.bonnet@u-pec.fr