FORMALISM OF DYNAMICS FOR COBOTS

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Keywords

Robotics, Rigid-body dynamics, Explicit formalism, Newton-Euler equations, Tree-chains, Closed-chains

Profile and skills required

Robotics, Multibody systems dynamics, Modeling, Mechanical Engineering, Mathematics applied to robotics

softwares: Maple or Mathematica or Matlab (Symbolic Math Toolbox) and / or programming in C language

Context

In the framework of the factory of the future, cobots (collaborative robots) are expected, with increased performances in terms of speed, quality and safety, whatever their mechanical architecture (single-chain, chain-driven robot tree, closed chain, mixed, with fixed or floating base). However, on the one hand, the detailed understanding of the phenomena and dynamic coupling for these systems is not yet achieved, on the other hand, the current robot control industrial architectures do not fully meet the needs mentioned especially in terms of speed, reliability, accuracy or safety.
One way to improve these two points is to revisit the formalisms of the dynamics of multi-body systems.
Indeed, the development of formalisms for writing dynamic models of active poly-articulated systems is essential on the one hand for the deep understanding of the dynamic effects involved and for their objective quantification, on the other hand for the simulation of the dynamic behavior of these systems and finally for the proper simplification of these equations in order to perform a real-time dynamic control of these systems.
Various research communities have deeply studied the field of multibody dynamics. As results, considerable improvements have been made in terms of generalization of the application field and in terms of reduction of the algorithm consumption. However, none of the formalisms suggested until now gives simultaneously a clear and direct relation between the physical parameters of the systems and the equations of motion. Indeed, generally expressed under a compact formulation, the equations of motion are nevertheless formulated using recursive processes or require heavy intermediate calculations such as the energy derivation and the acceleration energy development. Consequently, this kind of formalism cannot give directly a clear understanding of the dynamical phenomena acting on a general system in motion.
According to the previous considerations, it can be concluded that the complete comprehension of the field of multibody dynamics, more precisely of the equations of motion, has not been reached. Consequently, the equations of motion have to be formulated in a more suitable way respecting various constraints simultaneously. These constraints aim to improve the understanding of the inverse dynamics and can be defined as follows: the formalism of the inverse dynamics needs to (i) be analytical, (ii) be direct, i.e., no complex intermediate calculation and no recursive process, (iii) highlight clearly how the system's structural parameters are involved in the equations, (iv) be compact.
Therefore, reaching a formulation of the equations of motion which considers the previous constraints could allow for a better understanding of multibody dynamics. Based on the equations of Newton–Euler, a new formalism that satisfies the previous constraints has been developed by [41]. It was presented through two distinct forms. The first form shows that the inverse dynamics of a multibody system can be developed in a compact way which still highlights the relation between the structural

parameters and the dynamics of the system. In more details, using this first form, it is sufficient to introduce the system's structural parameters and to carry out few summations, to calculate directly each joint torque of a given system. This process does not require any intermediate calculation, such as energy derivation, or a recursive process. The second form straightly details for the first time the analytical expression of each torque due to the dynamic forces, i.e., the system inertia tensor, centrifugal forces, and Coriolis forces, and due to the environment forces, i.e., the external and gravity forces, in a suitable way easy to understand. Their expression have been developed according to the structural parameters and separated from the generalized velocities and accelerations.
This formalism of inverse dynamics was developed especially for a fixed base having a single kinematic chain with rotational joints.
Based on this formalism, a dynamic approach was developed for trajectories planning of a Mikron UCP710 multi-axis machining and a KUKA anthopomorphic robot [42].

Targets

The first goal is to improve the previous formalism to make it usable for systems with a floating base, and also with general joints (i.e., prismatic and/or rotational). The second goal is to extend the approach to closed and tree kinematic chains. The third goal is to consider the equations of motion with a new point of view. The idea is to the carry out the transformation of the dynamic and environment effects of the multibody system via the Jacobian tensor to simplify the readability of these equations and thus improve their understanding. The challenge is to produce a final form in which the equations of motion are carried out with only five simple physical entities: the Jacobian tensor, the generalized inertia tensor, the vector of external forces, the vector of joint velocities and the vector of joint accelerations. An assessment on the formalism complexity needs to be led. Moreover an adequate formulation will be developed in order to make the equations of motion usable to simulate the dynamic behavior of a system, and to be operable in real-time to control a robot. In order to validate the approach, the theoretical results will be applied on a mobile cobot equipped with two anthropomorphic arms.

Method

The existing formalism [41] will be extended for floating-based systems with rotoid joints or prismatic links. The guideline of the method will lead this formalism to:
- be analytical,
- be direct, that is to say without complex intermediate calculation and without recursive process
- clearly highlight how the system's structural parameters are involved in the equations
- be compact

Following the same principles, this formalism will be extended to closed and tree chains
At another level, in order to simplify the readability of the equations of dynamics and thus improve their understanding, the idea is to perform the transformation of the dynamic and environmental effects of the multi-body system via the Jacobian tensor. In their final form, the equations of motion will be formulated with only five simple physical entities: the Jacobian tensor, the generalized inertial tensor, the external forces vector, the articular velocity vector and the articular accelerator vector.
Analytical developments (symbolic computations) will be done under Maple, Mathematica or Matlab (Symbolic Math Toolbox).

Expected results

In addition to the different analytical forms obtained, an evaluation of their complexity will have to be carried out. Moreover a suitable formulation will be developed to make the equations of the movement usable to simulate the dynamic behavior of a system, and to be exploitable in real time to control a robot. In order to validate the approach, the theoretical results will be applied to a mobile cobot equipped with two anthropomorphic arms

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Modalities of supervision, follow-up of the training and advancement of research of the Phd student: The thesis will be supervised by Olivier Bruneau, professor at Paris-Sud University. Major goals will be set per quarter. A weekly meeting is scheduled on average to report progress. Daily monitoring will also be done according to the needs of the Phd student.

Valorization Targets to be achieved before the end of the thesis: 2 international conferences, 1 international journal accepted, 1 international journal submitted, local and national seminars.

Deadline for application: January 08, 2019

Web link : http://lurpa.ens-paris-saclay.fr/version-anglaise/phd-and-master-thesis-offers/

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Employer : Université Paris-Sud

French level required : A1 **English level required :** B1