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Multi-physics Modelling of a Compliant Humanoid Robot

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Introduction

In this article, we present a multibody model of the COMAN humanoid robot and of its walking environment[1]. The key features of the proposed model are:

1) an *efficient multibody dynamics* allowing short simulation computation time;
2) full *electromechanical model of compliant actuators* [1] made up with ordinary differential equations of the actuators inner dynamics;
3) reliable *mesh-to-mesh contact* processing in order to simulate the robot self-collision and contacts with the environment.

For deriving the multibody equations, the Robotran symbolic generator was selected due to its reliability and efficiency [2]. This work builds upon [3] by proposing a new actuator modeling and more powerful contact processing. This model proved to be useful to speed up the synthesis and tuning of movement controllers, and can easily be adapted to other robots simulations.

Multibody and multi-physics modeling

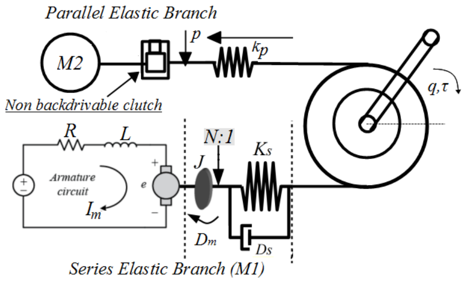

Figure 1: Compliant actuator electromechanical model

The second-order mechanical multibody model of the robot is derived in symbolic form by Robotran, and is provided in the general form:

$$M(q)\ddot{q}+C(q,\dot{q})+G(q)=\tau(q,\dot{q},q_m,\dot{q}_m)+\tau_p(p,q,k_p)$$

where q is the vector of angular joint positions, q_m and $\dot{q}_m$ are the vectors of motor position and velocity, $M(q)$ is the mass-inertia matrix, $C(q,\dot{q})$ and $G(q)$ represent Coriolis and gravitational forces and torques. $\tau(q,\dot{q},q_m,\dot{q}_m)=K_S(q_m-q)+D_S(q_m-\dot{q}_m)$ is the vector of motor torques applied to the links, K_S and D_S are the series spring stiffness and damping respectively. Electric actuators are often rigidly attached to the links to allow precise position control. In the present case however, flexible joints were developed, like in other advanced robotic systems, in which the motors are connected in series with a compliant element to provide better force control and also shock absorption against environmental impacts. Therefore the robot links actuated with such flexible joints are driven by the torques provided by the springs' deflections: $J\ddot{q}_m+D_m\dot{q}_m+\tau(q,\dot{q},q_m,\dot{q}_m)=K_t I_m$, where J is the motor inertia (including the rotor and moving parts such as gearbox), D_m is the motor mechanical damping, K_t is the torque constant, I_m is the motor current. The current dynamics are typically modelled as $L\dot{i}_m+RI_m+K_\omega\dot{q}_m=V$, where L,R,K_ω,V are motor inductance, resistance, back EMF constant and applied input voltage. Furthermore, the robot's legs are equipped with tunable springs going in parallel to the motors [1].

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These springs thus deliver a torque $\tau_p\left(p,q,k_p\right)$, where p is the controllable spring pretention and k_p is the spring stiffness. Figure 1 shows an electromechanical model of the whole actuator, i.e. including the series elastic branch and the tunable parallel spring.

In sum, such a model combines the electromechanical modeling of the robot links and actuators in a single multibody and multi-physics system of symbolic equations. This approach provides more realistic and efficient tools for both simulating the robot and also developing controllers being operational for a transfer to the real robot.

Compliant contact

Two approaches for contact modelling are widely used in multibody dynamics (see e.g. a review in [4]): rigid contacts and compliant contacts. Briefly speaking, rigid contact assumes that contacts between bodies are treated as instantaneous unilateral constraints without interpenetration of bodies. In contrast, compliant contact algorithms integrate contact processing within the multibody equations, through a compression and decompression phase. In this project, we selected a compliant contact library, developed within the Simbody software suite [5]. This choice was guided by the following reasons:

1) The parts of the COMAN contacting with the environment are covered by deformable (rubber) layers;
2) The Elastic foundation model (EFM) used in the Simbody library is proved to accurately approximate the continuous visco-elastic media [6];
3) The Simbody library allows using CAD meshes (in particular, triangular WaveFront mesh) for bodies in contact. In addition, EFM is not sensitive to the complexity of shapes (this is not the case for rigid algorithms).

Moreover, Simbody is open-source and distributed under permissive Apache 2.0 License, and can be coupled with any multibody engine. During our talk we will present how it is possible to efficiently couple the Robotran symbolic code and the Simbody contact library. This coupling can be used not only for humanoid robots, but also for any robotics system requiring compliant contact processing [7].

Figure 2: COMAN goes over a 3D bump.

Results

In the frame of this work, a fast and accurate model of a humanoid robot was derived. This model was used for the development of a dynamical bipedal gait on flat ground [8] and for monitoring its robustness to 3D obstacles (figure 2).

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[7] Example of a code is publicly available on https://github.com/TimotheeHabra/OffRoadRobot

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