ECCOMAS Thematic Conference on Multibody Dynamics
June 29 - July 2, 2015, Barcelona, Catalonia, Spain

Dynamic Analysis using Numerical Multi-body Approach for Quadruped Robots

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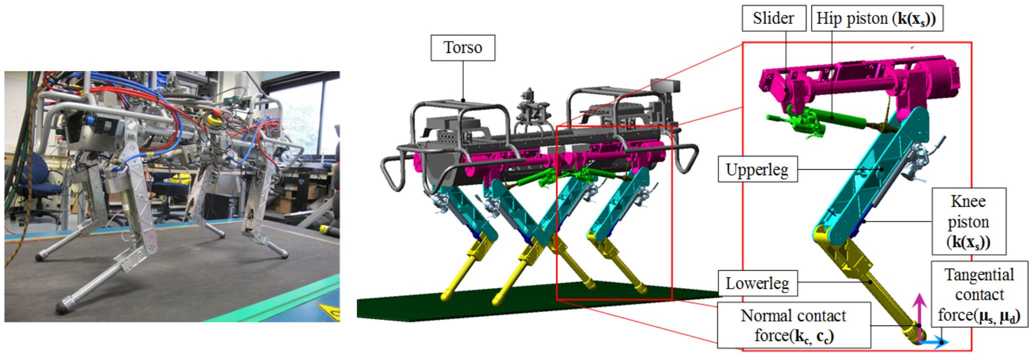
Abstract

The paper aims to introduce an advanced numerical platform able to reproduce a quadrupedal robot dynamics. Nowadays the panorama of quadruped robots is wide, it goes from robust to agile ones, from electrically to hydraulically actuated. They are capable of performing complex dynamic tasks like trotting, galloping and high speed running on uneven terrain. It is a challenge to deal with these dynamic capabilities because it is necessary to take into account the reciprocal effects between the mechanics and the control. So far in the traditional approach, mechanics and control are developed by means of two semi-independent models. Mechanics usually provides mechanism like bodies inertia and joints position to the control, while the control provides the resultant forces estimated without any structural effects to the mechanics [1]. These models usually interact only during the physical robot experimental test. If an error occurs at this stage, it is difficult to determine whether it is a problem of interaction or it is an internal problem within each model in itself. Our solution intends to overpass this issue by adding one step in the middle of the aforementioned process through a co-simulation between mechanism and control. That permits to have a well-rounded dynamic analysis in designing a performing robot.



(a) (b) (c)

Figure 1: Hydraullically Quadruped: (a) physical robot, (b) numerical platform. (c) Leg components.

The numerical platform presented here in inspired by the Hydraullically actuated Quadruped (HyQ) (Figure 1-(a)) [2]. It is based on the ***co-simulation*** between a ***multi-body model*** (MBM) and a ***control system*** with the aim to study a quadruped robot dynamics. Those are developed by using MSC Adams and Simulink software respectively.

The ***multi-body model*** deals with the mechanism dynamics and it takes in account several elements such as *system*, *environment*, *actuators* and *sensors*. The whole *system* is composed by Torso and four legs (Figure 1-(b)). Each leg (Figure 1-(c)) contains five rigid bodies with distributed inertia: Slider, Upperleg, Lowerleg, Hip piston and Knee piston. The internal constraints are cylindrical and translational connections, while the interaction with the external *environment* is represented by a contact law. It is established both by a normal and a tangential force. The normal force (Vertical solid magenta arrow in Figure 1-(c)) is modelled according to Hertzian law (Figure 2-(a)) where k_c is the stiffness, δ represents the penetration depth, n is an exponent and c_c is the contact force damping. The tangential force (Horizontal solid blue arrow in Figure 1-(c)) is modelled using a velocity-based on friction model (Figure

2-(b)) where μ_s and μ_d are the friction coefficients for static and dynamic conditions respectively while W represents the body weight. The *actuators* are modelled as non-linear spring according to the Equation in Figure 2-(c) where $K(x_s)$ is the non-linear stiffness, x_s represent the stroke position, β is the oil bulk modulus, A_i and V_i ($i = 1,2$) represent the chamber's area and volume respectively [3]. *Sensors* are computed by angle, position, velocity and acceleration measurements in the MBM.

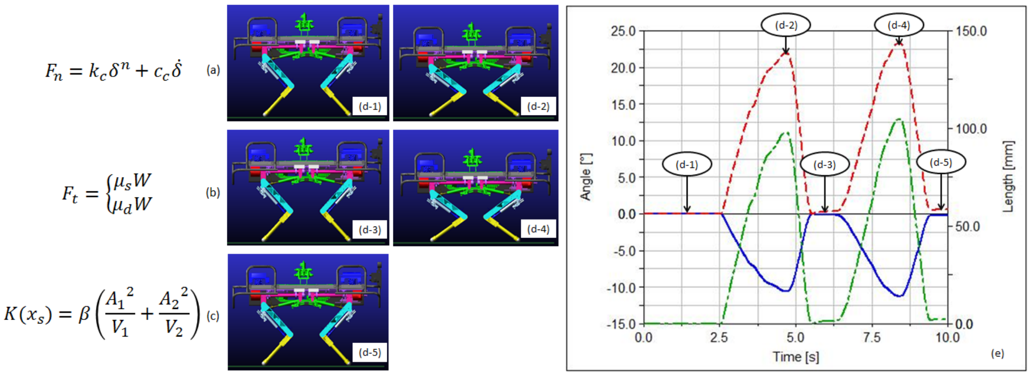


Figure 2: (a) Normal contact law. (b) Tangential contact law. (c) Non-linear spring law. (d) MBM push-pull movement. (e) Torso vertical displacement (green dash-dot line), relative angle between the Slider and Upperleg (blue solid line), relative angle between Upperleg and Lowerleg (red dashed line).

The ***control system*** architecture implemented in this platform concerns the legs PID control and it is called low level architecture. It is a position control which uses as input variables the *desired* and *actual* values of the two leg degrees of freedom angles. These are the relative angles between the Slider and Upperleg (HFE) and the relative angles between Upperleg and Lowerleg (KFE) respectively. The *desired values* are estimated in the MBM by means of an inverse kinematic analysis, while the *actual values* are measured by the MBM in a forward dynamic analysis.

At each ***co-simulation*** step, the control algorithm estimates the error between the aforementioned *desired value* and the *actual value* and sends back to the MBM the torque proper value to apply for the following step. The platform is tested by performing a sinusoidal vertical movement that consists in pushing-down and pulling-up the Torso (Figure 2-(e)). Adams/Solver (C++) uses an iterative, quasi-Newton-Raphson algorithm to solve the difference equations and obtain the values of the state variables. This algorithm ensures that the system states satisfy the equations of motion and constraint. The Newton-Raphson iterations require a matrix of the partial derivatives of the equations being solved with respect to the solution variables.

Future works concern the accomplishment of an extended campaign of experimental test to collect data useful for the model validation. It is also planned the fulfillment of the upper level architecture control, which deals with the equilibrium of the whole body during the locomotion, for testing several kinds of motions. The implementation of the squat jump will be a further development of the numerical model in order to analyze more complex dynamic tasks.

References

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