RBDL and MUSCOD-II: A One-legged Hopping Robot

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This is a simple example that should get you started with MUSCOD and RBDL. It is devoted to the introduction to contact forces and multi-phase optimal control problems. To this end we consider a simple one-legged hopping robot, see Figure 1.

The hopping robot consists of two rigid bodies, the *Body* and the *Leg*. The robot has two degrees of freedom:

- q_0: the height (i.e. Z–coordinate) of the body *Body*.
- q_1: the retraction of the body *Leg*.

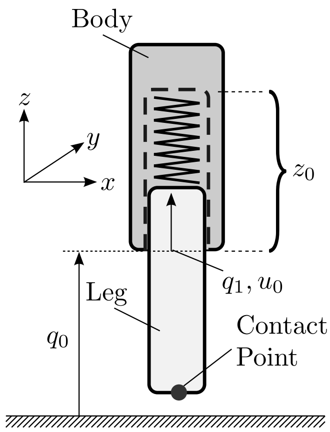

Figure 1: One-legged Hopping Robot

The two elements bodies are connected by a prismatic joint and a spring. In the case of maximal extension of the leg, i.e. $q_1 = 0$, the spring is fully extended to length z_0. The translation of the robot's leg can be controlled by the linear force in the control u_0.

In addition to gravity and interior forces of the actuated joints, it is important to also model external ground reaction forces during the contact phase. Furthermore, we want to be able to model contact gains due to collisions.

Here, the collision is modeled as an instantaneous event that results in discontinuities in the velocities. In MUSCOD-II this can be modeled using "Transition Phases" that have zero duration and are specified by using the `def_strans` pseudo-integrator in the DAT-file.

This leads to three different contact phases for the robot: the *flight* phase, the *collision* transition phase, and the *contact* phase (see Figure 2).

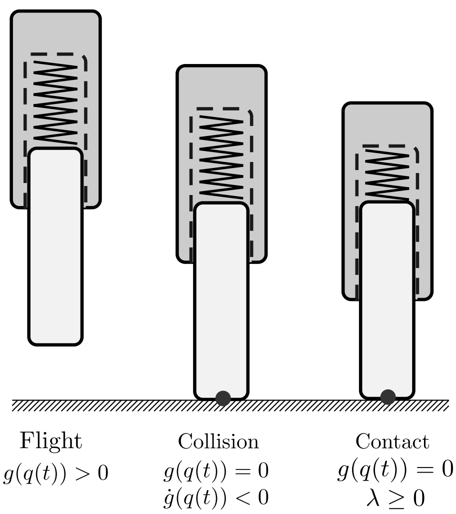

Figure 2: Overview of the three phases

The three different phases a characterized by the following properties:

Flight Phase: There is no contact with the ground ($g(q(t)) > 0$) and there are no external forces.

Collision Transition Phase: The contact condition $g(q(t)) = 0$ is fulfilled. In addition, the contact point is moving along the negative contact normal. Note, that collisions in general result in discontinuities in the velocity variables.

Contact Phase: The contact condition $g(q(t)) = 0$ is fulfilled and there are positive ground reaction forces λ in the direction of the contact normal.

All phases can be modeled using RBDL. For details we refer to the official documentation (Section "'External Contacts"').

Tasks

Determine an optimal control, such that the robot performs a periodic motion with a (vertical) velocity of $v > 5$ at take of.

1. Define the model name and the correct integrators for the individual phases in the DAT-file (`libind`).
2. Complete the function `update_generalized_variables` that copy the values from the `double` arrays to the correct Eigen vectors `Q, QDot, Tau` that are then used by RBDL methods.
3. Complete the right-hand side function stubs `ffcn_flight`, `ffcn_touchdown`, `ffcn_contact`.
4. Define the point constraints `rdfcn_*` and `def_mpc()`.
5. Optimization 1: Minimize the applied force u_0 during the whole process.
6. Optimization 2: Minimize the collision impact.