Optimization of Gaits with a Soft Contact Model

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I. Introduction

Model-based gait optimization is typically performed on robot models that describe foot-ground interactions through fully rigid contacts (e.g. [1], [2]). They are considered superior to soft contact models, as those can lead to stiff differential equations and require an empirical identification of contact model parameters. The advantages of rigid contact models, however, come at the cost that their discrete nature makes the automatic discovery of different gaits with different contact sequences difficult. In this work, we study the trade-offs of this modeling choice specifically in the context of gait optimization. We derive a soft contact model based on our robot hardware and compare it to a rigid contact model while finding optimal motions for a one-legged hopper.

II. Contact Models

Our contact models were designed to represent the feet that are used in the legged robots Starl*ETH*, RAM*one*, and RAM*bi*. These are spherical and made from soft rubber.

a) Soft Contact Model: In the normal direction, our soft contact model was based on the experimental data of a series of foot-drops reported in [3]. We identified the following structure:

$$\lambda_\mathrm{N}(\delta_\mathrm{N},\dot{\delta}_\mathrm{N}) = \begin{cases} 0 & ,\delta_\mathrm{N} \geq 0 \\ f_\mathrm{s}(\delta_\mathrm{N}) + f_\mathrm{d}(\dot{\delta}_\mathrm{N})s(\delta_\mathrm{N};\hat{\delta}) & ,\hat{\delta} < \delta_\mathrm{N} < 0 \\ f_\mathrm{s}(\delta_\mathrm{N}) + f_\mathrm{d}(\dot{\delta}_\mathrm{N}) & ,\delta_\mathrm{N} \leq \hat{\delta}, \end{cases} \quad (1)$$

with the normal deformation $\delta_\mathrm{N} = c_2(t) - r_\mathrm{foot}$, quadratic stiffness f_s and nonlinear damping f_d. The transition function s together with the smoothing coefficient $\hat{\delta}$ are determined by the parameters of the nonlinear spring-damper model.
Our model in the tangential direction is based on the model proposed in [4]. The parameters of this tangential model $\lambda_\mathrm{T}(\delta_\mathrm{N},\delta_\mathrm{T},\dot{\delta}_\mathrm{T})$ (equation 10 in [4]) were identified in walking experiments.

b) Hard Contact Model: The rigid contact model in the hybrid dynamics description is characterized by a holonomic non-slipping constraint while the foot is in contact with the ground.

c) Model Verification: Both models were implemented in a forward dynamic simulation of the quadrupedal robot RAM*bi*. The soft contact model resembled reality much closer.

III. Trajectory Optimization

Both contact models were implemented for gait optimization of a monopedal robot (Fig. 1a) [1]. We chose the overall thermal losses in the motors as the objective function.

To be able to incorporate the hybrid dynamics caused by the hard contact model, a direct collocation scheme was carried out, similar to the one presented in [2]. Our implementation exploits the sparse structure of the problem, analytic gradients, and uses mesh-refinement to yield more precise system dynamics. For the rigid contact model, a series of phases with discrete transitions was defined, while only a single phase was used for the soft contact model.

The locally optimal gaits that were found for both models are shown in Figure 1b. They closely resemble each other.

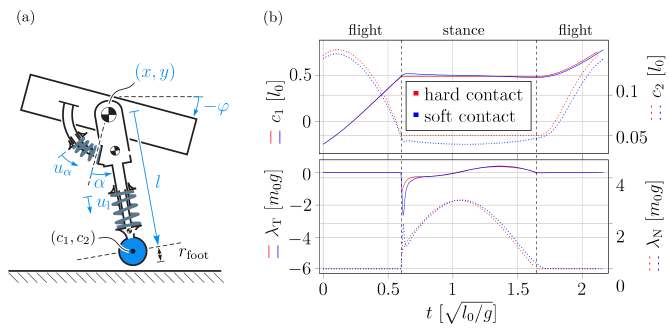

Fig. 1. (a): 7 degrees of freedom robot with series elastic actuators. (b): (Locally) optimal trajectories of both contact models with start and finish at apex-transit $y = 1.2$, $\dot{x}_\mathrm{periodic} = 0.5$. The dashed vertical lines indicate the transition between phases of the hard contact model.

IV. Conclusion

The soft contact model identified in our work is showing substantial compliance. This compliance is physical and not an artifact of trying to generate a model that 'behaves well' numerically. In fact, the soft contact model was resembling experiments much closer than the rigid contact model. The optimization performance of the soft contact model was comparable to that of the hard contact model. While our results are still preliminary in nature, they show that a soft contact model can potentially be used in gait optimization. The optimization with a soft model is contact invariant, which is a big advantage if the optimal sequence is unknown a priori.

References

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