Adaptive Control of a Spring-Mass Hopper

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Abstract – Practical realization of model-based dynamic legged behaviors is substantially more challenging than statistically stable behaviors due to their heavy dependence on second order system dynamics. In this paper, we present an on-line, model-based adaptive control method for running with a planar spring-mass hopper based on once-per-step correction scheme.

SUMMARY

Even though dynamic models for which we have a sufficiently good analytical understanding can support physically relevant controller designs, the measurement and estimation of particularly the dynamic parameters, such as spring and damping constants for flexible components of a robotic platform, is still a challenging problem. Fortunately, this issue is not confined to the control of legged locomotion and received considerable attention from the adaptive control community [1]. Motivated by work in this area, this study presents a new model-based adaptive control method for running with the well-known Spring-Loaded Inverted Pendulum (SLIP) model (see Fig. 1), emphasizing on-line estimation of unknown or miscalibrated dynamic system parameters.

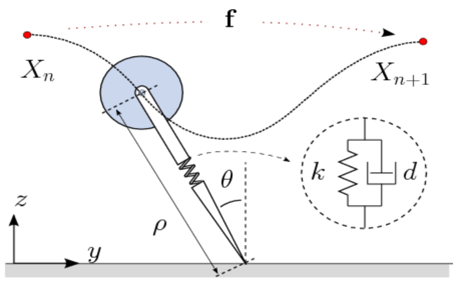

Fig 1. The Spring-Loaded Inverted Pendulum (SLIP) model. Dashed curve illustrates a single stride, defining the return map $X_{n+1} = \mathbf{f}(X_n,\mathbf{u}_n)$

In the presence of a sufficiently accurate model, gait control of the SLIP model can be achieved through a deadbeat strategy as described in [2]. Given a desired apex state X^*, inversion of the apex return map yields the controller $\mathbf{u} = f^{(-1)}(X^*, X_n)$. Note, however, that the approximate return map and hence its inversion can only rely on possibly inaccurate parameter estimates for spring and damping constants.

The core of our adaptive control strategy relies on once-per-step corrections to these estimates based on the difference between predicted and measured apex states for each stride. This corrective parameter adjustment is very similar to how estimation methods such as Kalman filters use innovation on sensory measurements to perform state updates [3].

Fig 2. illustrates the block diagram for the adaptive parameter correction scheme we propose. Our method relies on the availability of an approximate return map **g** that can predict the apex state outcome of a single stride. In this study, we consider two alternatives for this approximate predictor model:

1. *Exact SLIP Model (ESM):* This option predicts the outcome through numerical simulation of SLIP dynamics.
2. *Approximate Analytical Solution (AAS):* This option uses analytic differentiation of AAS derived in [2].

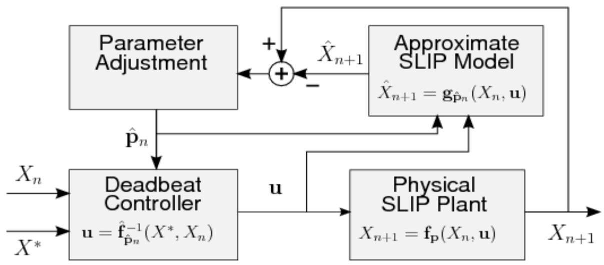

Fig 2. The proposed adaptive control strategy. Prediction errors of an approximate plant model g are used to dynamically adjust parameter estimates.

In order to test our algorithm, we run a large number of simulations using different ranges of system parameters. We then define three error measures where SSE_k & SSE_d capture system identification performance and SSE_a characterizes the tracking performance of the adaptive controller. Table I summarizes the average apex state tracking and parameter estimation errors and their standard deviations across all simulations.

Table I. Percentage apex tracking and parameter estimation errors

Error Measure:	SSE_a	SSE_k	SSE_d
Non-adaptive	6.56 ± 4.64	10 ± 6.20	10 ± 6.20
AAS Adaptive	0.002 ± 0.001	2.34 ± 1.45	5.53 ± 2.81
ESM Adaptive	0.52 ± 0.45	0.0008 ± 0.0005	0.007 ± 0.005

In this study, we proposed a novel adaptive control algorithm to both support on-line identification of unknown dynamic parameters and improve steady-state tracking performance of previously proposed control algorithms for SLIP model

REFERENCES

[1] K. J. Astrom et.al., *Adaptive Control*, Addison-Wesley Longman Pub., 1994
[2] U. Saranli et.al., *Approximate Analytic Solutions to Non-symmetric Stance Trajectories of the Passive SLIP with Damping*, Nonlinear Dynamics, 2010.
[3] D. Simon, *Optimal State Estimation*, Wiley, June 2006.