A Novel Approach to Solve Predictive Simulations in a Stochastic Environment

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Predictive simulations of human movement, such as walking [1], do not predict all features when minimizing muscular effort. These simulations ignore the noise in the system and solve the problem in a deterministic environment, which does not yield the optimal solution for a stochastic nonlinear system, such as a human with muscles. Recent studies suggest that noise helps to explain certain human movement strategies (e.g. [2]). Thus, predictive simulations may better reflect human movement when taking into account noise. However, trajectory optimization of stochastic nonlinear systems has been solved only for certain special cases (e.g. [4]).

In this abstract we propose a new approach to optimize a trajectory in a stochastic environment, using direct collocation. Then, multiple episodes of some task, each with noise, are optimized. The controller consists of time-dependent open-loop control with feedback. The total effort is minimized over all episodes. Using direct collocation, the decision variables are the states at all time points of all episodes, and the controller parameters.

This concept is demonstrated on a pendulum swing-up problem. The pendulum has one degree-of-freedom, the angle between the ground and the pendulum. The torque at the base controls the pendulum. Noise is added to the angular acceleration. The objective is to swing the pendulum up in 10 seconds, minimizing the squared torque.

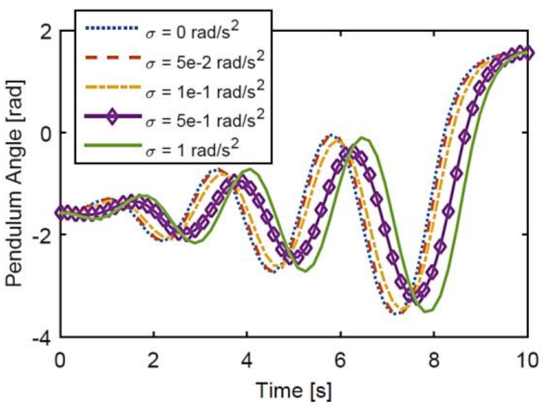

Figure 1 - Optimal trajectories that were found with different noise levels. With increasing noise, the final swing-up occurs later in time.

Figure 1 shows the optimal swing-up for different levels of variance. One can see that the swing-up occurs later with increased noise variance. This is expected, because more control torque is required to keep the pendulum in this unstable equilibrium in a noisy environment, so less time is spend near the upright position.

We also show that co-contraction is optimal for certain tasks that minimize effort. To do so, two same Hill-type muscles are used to control the pendulum. The objective is to keep the pendulum upright in a noisy environment. Three control parameters are optimized in this symmetric problem, an open-loop control input, the co-contraction, and a position and derivative feedback gain.

This novel approach for predictive simulations of human movements will be used in predictive simulations of walking. Co-contraction of muscles can then be predicted, for example in the upper leg of a below-knee amputee. Also, prostheses and exoskeletons can benefit from this approach. A controller with muscle-like behavior can be optimized using this approach, such that it uses stabilizing muscle properties to minimize required torque.

References

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