Pivoting a Partially Unknown Object about an Environmental Contact

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I. Introduction

A common mode of failure when using model-based approaches to manipulation is deviation between the actual and predicted contact mode (i.e., contact, no-contact, sticking, sliding) sequence. For example, unintended slipping between the pusher and slider during a horizontal pushing task results in poor tracking of the planned trajectory [1]. Moreover, unintentional slipping between the object and the ground during a pivoting task can also results in failure [2].

These deviations in mode-sequence can be difficult to observe, and when observed, difficult to rectify (e.g., requiring hybrid control [3]). This is particularly true in the pivoting task, where mode deviations can occur at environmental contacts. In this case, the contact location, mode, and forces are not directly observable and must be inferred based on object information (e.g., a first-principles or learned model of the object). This prediction, however, is susceptible to error from poor estimation and model imperfections.

Here we focus on combining online system identification and state estimation with model-predictive control (MPC) to pivot an object with unknown parameters about a sticking external contact. Online parameter estimation enables a more accurate prediction of the environmental contact forces, allowing for better regulation of the predicted contact mode.

II. Problem Scenario

We apply our approach to a system where a rigid object is balanced on one of it's corners against the ground. Our objective is to manipulate the object's center-of-mass to a desired orientation with respect to the ground (e.g., the vertical, Fig. 1) using an end-effector that maintains a sticking line-contact with an edge near the object's top.

We assume both robot and environmental contacts obey Coulomb friction, and currently, both coefficients of friction and the length of the robot line-contact are known. Other object parameters are assumed to be unknown. Finally, we currently limit the robot to exerting forces that maintain sticking contact at both contact interfaces.

III. Methodology

We develop a *real-time* framework that consists of two components: (1) an extended Kalman filter (EKF) to estimates both the object's state and governing parameters of the system's dynamics, and (2) a linear MPC that finds a sequence of robot forces that drives the system to the goal state while maintaining sticking contact at both interfaces.

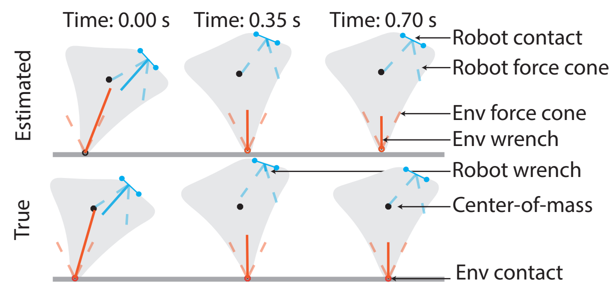

Fig. 1. A simulated object with uncertain parameters is driven to the upright configuration by a robot that makes a sticking line contact one of it's edges. The top row shows the estimated system, and the bottom row shows the true system.

The EKF estimates the external contact's location, the object's inertial properties, the relative of position of the object's center-of-mass, and the object's state. It relies on measurements of both the end-effector pose and the forces it applies to the object. We then make a linear approximation of the *estimated* system about the goal state. The MPC uses the approximate system to find a policy that drives the object to the goal state while obeying kinematic and wrench constraints. The MPC is solved on a 20-step horizon, and our framework operates at a frequency between 20 Hz to 40 Hz.

IV. Initial Simulations

Here we show an example of our framework driving the center-of-mass of an object balancing about an environmental point contact to the vertical. Snapshots of the object's motion and the contact forces are shown in Fig. 1. The initial guesses for both the object's state and the system's parameters are drawn from a uniform distribution centered at their true values. Note that only a subset of the system parameter converge to their true values as (1) there are more parameters than can be observed, and (2) the system reaches the goal before the parameters estimates can converge. However, this is acceptable state estimate is still accurate and our object is to drive the object to a goal state.

V. Conclusions

In summary, we've shown a method for pivoting an object with uncertain parameters about an environmental point contact. By enforce sticking at both interfaces, we are able to estimate relevant system parameters in real-time and drive the object to the goal state. A complete solution, however, requires considering different contact modes (i.e., slipping, no-contact) at both interfaces, and we are currently developing a framework that allows slip at the environmental contact.

REFERENCES

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