Hand-arm coordination for robot interaction tasks

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In most robotic manipulator applications the manipulator is endowed with a jaw gripper, grasps an object rigidly, and then performs motion while maintaining the rigid grasp. While simplifying the manipulation problem, this approach often results in unnatural movements due to restricted manipulability. The objective of this research project is to develop control algorithms which enhance the manipulability of the arm-hand-object system by extending control algorithms designed solely for the arm to the case when the object is allowed to move in-hand. The initial focus is on the regrasping problem with an in-hand object. The proposed approach for controlling in-hand motion is to be extended to other manipulation tasks like door opening.

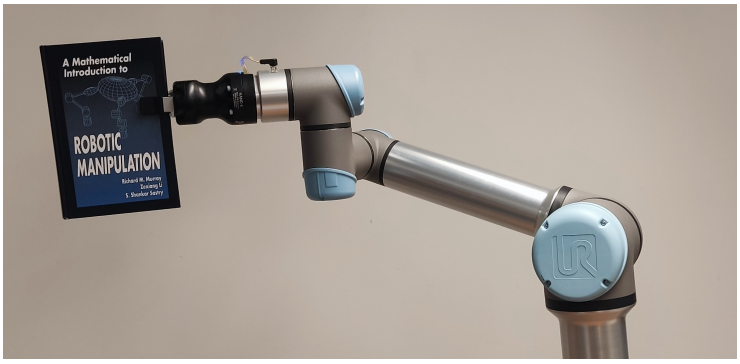

Figure 1: The UR5e manipulator endowed with a jaw gripper holding an object.

Regrasping is a type of robotic manipulation whose goal is to change the pose of an object with respect to the robotic hand holding it. An example robot holding an object is shown in figure 1. In the case of simple grippers like the jaw gripper, regrasping can be categorized as nonprehensile manipulation, meaning that the manipulation of object is achieved not through intricate finger motions, but by pushing, sliding and pivoting. These movements are obtained by leveraging the dynamics of the object, friction and gravity. One such movement is a swing-up, shown in Figure 2.

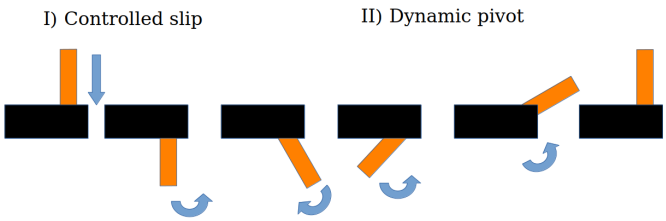

Figure 2: Shematic view of a swing-up. The black rectangle represents the gripper, while the orange rectangle represents the grasped object. The manipulator is omitted for visual clarity.

This setting introduces several challenges: underactuation, non-holonomic constraints, possibly unstable numerics due to friction, and difficult estimation in the hardware implementation. Underactuation refers to the fact that the object can not be directly controlled, i.e. instantaneously moved in arbitrary direction. This makes trajectory generation the critical problem to be solved.

Our approach can be summarized as follows. We propose modelling of the in-hand object as a semi-actuated joint at the end of the manipulator's kinematic chain. The control input consist of manipulator's joint torque and the gripper's grasping force, while the state is comprised of the manipulator's joint angles and the object's in-hand pose. Next, we propose the use optimal control to generate dynamically feasible trajectories to achieve the desired regrasp. The generated trajectory can then followed either with an MPC formed from the initial problem, or a trajectory-tracking controller. To address the numerical issues, we are working on augmenting off-the-shelf DDP-style optimal control solvers with implicit integrators. Finally, we will employ a custom gripper to obtain quick and accurate haptic estimation of the object's state.