Mitigating Human Uncertainties in Human-Robot Collaborative Transportation with Whole-Body Dynamics

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Motivation. Collaborative human-robot systems can significantly reduce human workloads. One frequently encountered task in engineering settings is object transportation [1]. To employ a human and a mobile robotic arm to perform co-transportation, the key challenges arise from the uncertainties of human behaviors, which may not adhere strictly to optimal trajectories, and the increased control complexity due to the coupling of the robotic arm and its mobile base. To address these issues, our goal is to develop a new control scheme that can efficiently compensate for human uncertainties. The approach offers two benefits: (i) the controller leverages the whole-body dynamics of the robot to achieve better end-effector mobility, rather than performing separate control on the robot arm and the mobile base [2]; (ii) the robot's pose is informed by the specific ways in which humans cause uncertainties, instead of compensating them passively [3].

Problem Statement. As illustrated in Fig. 1, the task is to enable a Fetch robot and a human to cooperatively transport a board to a target position. In this process, the board needs to be horizontal and follow a desired nominal trajectory which is known to both the robot and the human. Nevertheless, humans are subject to uncertainties, implying that the actual trajectory might deviate from the planned one, necessitating the robot to adjust accordingly. We assume that human uncertainties can be characterized by random noise following certain distributions determined by individual human preferences, i.e., some humans will introduce more noise on the z-axis, requiring the robot to compensate for the levelness of the board; some will introduce more noise on the x, y-axes, requiring the robot to adapt to a new trajectory moving to the target. While these types of uncertainties need different control strategies to compensate, the problem of interest is to design an algorithm based on the whole-body dynamics of the robot and informed by human preferences so that the robot can use minimum control effort and best adapt to human uncertainties in corresponding directions.

Main Results. To evaluate task performance, we consider a stochastic quadratic cost function that incorporates both tracking errors and control efforts, while taking an expectation over the distribution of human uncertainties. It is known that the pose of the robot determines the system's transition matrices and influences the mobility of the end effector in different directions. Therefore, to minimize control cost, our control algorithm not only designs a receding horizon linear quadratic tracking controller over the robot's whole-body dynamics but more importantly, also incorporates an optimization algorithm to optimize the pose of the robot.

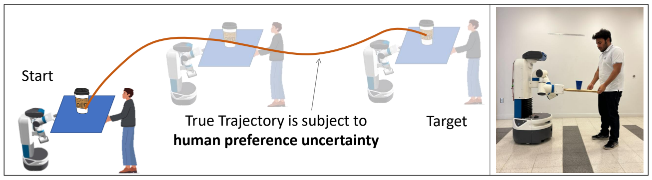

Fig. 1: Task: Fetch robot and human co-transportation.

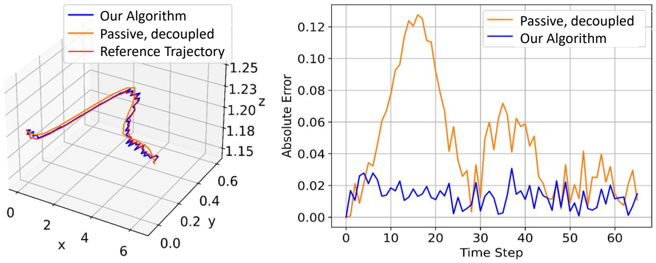

Fig. 2: Comparsion of tracking performances

Our algorithm has been implemented in the Gazebo simulator for validation purposes. Fig. 2 is a representative result among numerous simulations we have performed, considering human uncertainties primarily occurs on x, y-axes and, to a lesser extent, on z-axis. The figure compares our human preference-informed whole-body control method with a controller that passively adapts to human uncertainties and employs decoupled control on the robot arm and the mobile base. The figure provides both 3-D trajectories and the tracking error measured by Euclidean distance. It can be observed that the developed method generally performs better in tracking errors and has significant advantages when handling sharp turns. This is mainly because the whole-body dynamics enable actuators in the arm and mobile base of the robot to compensate for each other's mobility constraints. In addition, pose optimization prepares the robot for a beneficial pose in advance, enabling it to respond more efficiently to unexpected human behaviors. While our current simulated experiments assume access to the full state information in the world frame, moving to the hardware platforms, we are designing controllers using the robot's local sensory inputs.

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