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Motion Planning and Control of Ladder Climbing on DRC-Hubo for DARPA Robotics Challenge

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Abstract— **This video presents our preliminary work towards addressing the ladder climbing event in DARPA Robotics Challenge (DRC) using DRC-Hubo robot. A ladder-climbing motion planner is developed which generates a collision-free, stable quasi-static trajectory for execution. Compliance control is enabled on arm joints to compensate for the calibration error, modeling error and control error. We have demonstrated that DRC-Hubo can robustly climb a variety of ladders in simulation and successfully climb a ship ladder on the hardware.**

I. Introduction

We present our undergoing work for the ladder climbing task in DRC whose goal is to provide robots human-like navigation, manipulation and perception capabilities in dangerous, degraded, and human-engineered environments. We are using DRC-Hubo as the platform, which is a full-size humanoid robot designed and built by Rainbow Co. specially for Team DRC-Hubo participating in DRC track A competition. The video shows the following: 1) motion primitive based ladder-climbing planner and compliance control; 2) DRC-Hubo robustly climbing various ladders in simulation and hardware verification on a standard ship ladder.

II. Open-loop System Pipeline

Our preliminary work focuses on enabling and verifying the capabilities of ladder climbing for DRC-Hubo. For simplicity, we assume the ladder specification, relative robot-ladder position and orientation are known. Our system includes the following major modules:

1) Ladder-Climbing Planner[1]: takes the parameterized ladder specification, relative robot-ladder position and orientation as input, and outputs a collision-free, stable quasi-static motion for climbing the ladder.
2) hubo-ach: a low-level controller for DRC-Hubo based on ACH Inter-Process Communication library [2], [3]. The compliance control is implemented in this module.

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III. Ladder-Climbing Motion Planner

We have developed a ladder-climbing motion planner based on the idea of motion primitives. A motion primitive is a solution to one sub-task of the motion-planning problem. The ladder-climbing motion can be divided into a sequence of climbing actions with each finishing one sub-task: hands reaching higher on the rail, feet moving to a higher rung, etc. Each motion primitive, designed by human expert, contains prior knowledge, e.g., hand/foot contacts, robot poses to keep balance, waypoints to avoid collision, for solving a specific action. The planner utilizes motion primitives as seeds to generate a motion for the new environment.

IV. Compliance Control

Ladder-climbing motion for a humanoid robot usually involves four limbs in contact. These contacts form multiple closed kinematic chains which make the motion sensitive to calibration, control and modeling errors. Simple joint-space control does not work since even small errors can cause excessive contradictory force on the joints, which will shut down/damage the motor. To solve this, we have developed a compliance controller, which controls the current indirectly by limiting PWM on motors to adjust output torque, to enable compliance on the arm joints to compensate for errors.

V. Experiments & Conclusion

Our ladder-climbing motion planner is proven to be able to solve for various ladders, including A-frame ladders, regular ladders and ship ladders in simulation. Particularly, within 2 minutes cut-off time, it can solve most (72%) of the regular ladders with inclination from 70° to 90° and rung spacing from 20cm to 35cm with 1°/1cm increment respectively.

We also have verified our strategy on a standard industrial ship ladder, which is similar to the one specified by DARPA for DRC using hardware. The motion planner generates a collision-free and stable trajectory within 15 seconds and the motion execution is finished in 7 minutes by DRC-Hubo in open-loop. The compliance control was verified to be able to compensate for errors caused by multiple factors.

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