Peg-in-hole manipulation of the Baxter dual-arm robot

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ABSTRACT

This work developed a hybrid velocity/force control solution to the fine manipulation Peg-in-Hole task, using the compliant dual-arm Baxter robot. Real-world environments robot manipulators operate in are typically unknown with uncertain goal poses. Further, passively compliant robots like Baxter suffer from poor positional accuracy. To overcome these drawbacks, a hybrid velocity/force control framework was established in this work. It divided the problem into three discrete phases: 1) Motion in free space; 2) Search, and; 3) Insert. A PID velocity controller was developed to control and constrain motion, while force/torque feedback from a wrist-mounted sensor allowed the robot to adapt to its unknown environment. Filtering was applied to the force/torque data to reduce the effect of noise and improve the PID control. Finally, a state machine was designed to implement the control methodology and adapt the end effector movement for each stage of the task. The results demonstrated that the solution was able to insert the peg into the hole with a radial clearance of 1.5 mm in approximately 37 seconds, comparable to other works.

INTRODUCTION

Since the advent of robotics, manipulation has been a key feature and extensively researched. The Peg-in-Hole (PiH) assembly task is a well-covered, challenging research area pertaining to fine manipulation. It is widely used as a benchmark for different solutions because the goal pose is often unknown and uncertain.

Popular approaches to the PiH task include impedance control (Zou et al. 2019) and hybrid position/force control (Raibert and Craig 1981). Impedance control benefits from active compliance but relies on high positional accuracy to avoid error propagation. Hybrid position/force control decouples position and force but also requires high accuracy. The hybrid velocity/force control method developed in this work built upon the hybrid position/force method to instead use velocity control to overcome the position error of the compliant Baxter robot.

This work first tested position control of the Baxter robot and confirmed its poor suitability for this task. It then tested velocity control and developed a PID velocity controller to improve the velocity control of the Baxter arms. The velocity controller was combined with feedback from a wrist-mounted force/torque sensor (FTS) to achieve decoupled velocity/force control. This allowed the robot to restrict motion to one or two degrees of freedom (*e.g.* up/down) while also monitoring force in certain directions. Additionally, a filter was developed to reduce the effect of noise from the FTS. Finally, this hybrid velocity/force control method was applied to the round PiH task through a state machine with the aim of satisfying two objectives: a) implementing velocity control of the Baxter joints and; b) using a hybrid velocity/force control model to achieve the PiH task.

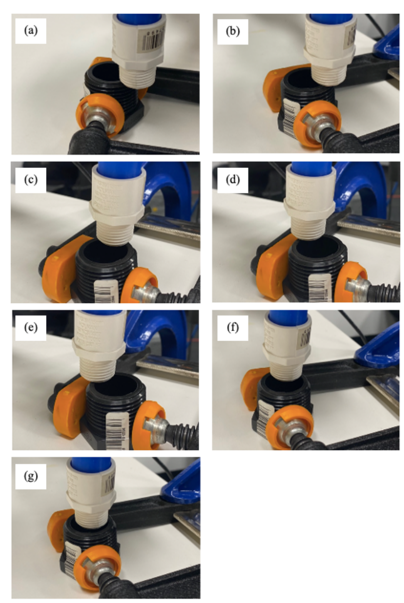

Figure 1. Search phase of the PiH task using hybrid control

RESULTS AND DISCUSSION

The hybrid velocity/force control solution was implemented on the Baxter robot through the use of a state machine. This clearly defined the end effector motion behaviour for the three phases of the PiH task: 1) motion in free space; 2) search and 3) insert. Figure 1 shows the Baxter robot performing the search phase. It moved in the positive y-direction (a-b), incremented in the positive x-direction, moved back in the negative y-direction (c-d), incremented in the positive x-direction (e-f) and finished this phase at (g) when the normal force dropped below the threshold value. At this point it began the final insert phase.

Figure 2 shows the end effector pose in the z-axis throughout the PiH task. The PID controller performed well by keeping the pose relatively smooth throughout the task. The graph indicates that the arm began lowering at 7.5 s and continued until 15 s when it made contact with the hole surface. It then performed the grid search until 35 s when a drop in normal force was detected and the final phase, insertion, began. The peg was lowered for approximately 1 s. Between 36 s and 43 s the robot performed the torque tests to ensure the peg was correctly inserted into the hole and had not simply slipped off the hole surface. The large increase in the z-position at 43 s indicates the peg being removed from the hole after successful insertion. Overall, the hybrid control method satisfied both objectives defined at the beginning of this work, achieving peg insertion in approximately 37 s on a round peg/hole pair with a radial clearance of 1.5 mm.

The main limitations of this solution are that if the end effector is not raised approximately over the hole it will fail to find it until it is placed in an improved starting position. Additionally, other geometries, smaller clearances and more difficult hole orientations were not tested using this model.

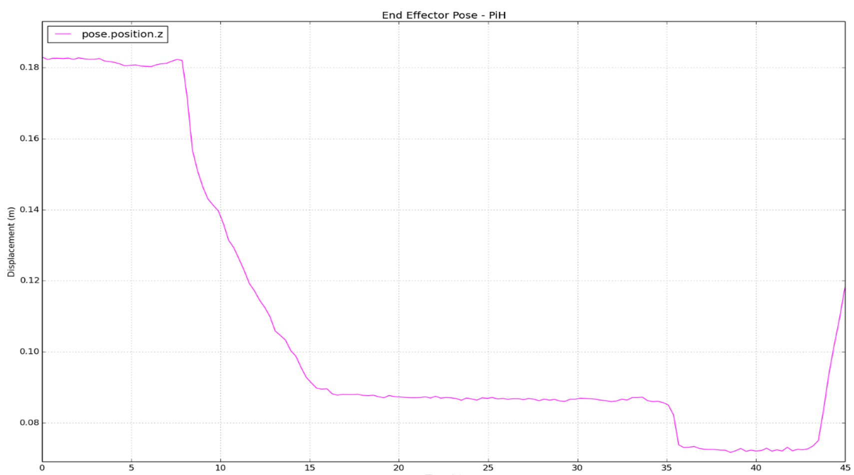

Figure 2. End effector pose in z-axis during PiH task

CONCLUSIONS

A successful hybrid velocity/force control solution to the fine manipulation Peg-in-Hole task was developed in this work. The model was validated on the compliant dual-arm Baxter robot and produced successful results. It completed the task in approximately 37 s, using a round peg/hole pair with a radial clearance of 1.5 mm. The main limitations to this model are that it requires the human user to place the end effector approximately over and normal to the target hole and only used one of the Baxter arms. Future works can build upon this solution by integrating the second arm to hold the hole and bring the two pieces together regardless of starting position. Further, the model can be expanded to control both arms in unison.

REFERENCES

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