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Multi-Joint Robot Transfer System in Three Dimensional Space

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ABSTRACT

Transfer system in three-dimensional space, the use of multi-joint robot arm provides much flexibility. To realize quick point-to-point motion with minimal sloshing in such system, we propose an integrated framework of trajectory planning and sloshing suppression. The robot motion is decomposed into translational motion of the robot wrist and rotational motion of the robot hand to ensure the upright orientation of the liquid container. The trajectory planning for the translational motion is based on cubic spline optimization with free via points that produces smooth trajectory in joint space while it still allows obstacle avoidance in task space. Input shaping technique is applied in the task space to suppress the motion induced sloshing, which is modeled as spherical pendulum with moving support. It has been found through simulations and experiments that the proposed approach is effective in generating quick motion with low amount of sloshing.

Keywords: *Transfer System of Multi-Joint Robot in Three Dimensional Space*

INTRODUCTION

In this research, we address a case where a robot arm is used to move a liquid filled container in three-dimensional space. Some example application cases for this setting are transfer of molten metal in casting industries and liquid containers handling by service robots. The use of articulated robot arm with high degree of freedom for these purposes provides more dexterity and flexibility when compared with the more dedicated type of liquid transfer devices. There are two main performance characteristics to consider in this system: quick motion and minimal sloshing. Those two criteria are conflicting, as quick motion tends to generate much sloshing of the contained liquid. Sloshing may cause the liquid to spill out of the container, and in the case of molten metal too much sloshing may affect the physical properties of the liquid. Moreover, other task, for example, pouring, cannot be performed when residual sloshing still occurs, thereby potentially reducing the system productivity. Thus the challenge in this problem is to generate trajectories with concurrent consideration of motion time minimization and sloshing suppression for point to point motion in a three-dimensional working space where static obstacles may exist.

The motion speed of robot arm is mainly constrained by its kinematic and dynamic limit of the joints. One method to generate trajectories for such system is by posing the optimal control problem as a nonlinear optimization problem where the system states are discretized in some way. To reduce the large solution space and its associated computation time, the trajectory is often parameterized into a known structure, for example, polynomial function. Among the polynomial splines, cubic spline is the lowest order polynomial trajectory that guarantees continuation in acceleration and velocity as well as limited jerk. Higher order polynomials would result in smoother profile but longer motion time, while lower order ones would result in unlimited jerk.

Most of them try to optimize either the motion time or the location of knots, depending on the application needs. Relatively few addressed the optimization of time and location of knots concurrently. In the latter approach, the location of knots is not fixed, which is suitable for trajectory planning problem with obstacle avoidance. In addition, it often results in a quicker motion because there is less restriction for the optimization algorithm to reach optimal velocity profile.

The smooth cubic spline trajectories induce less vibration when compared to nonsmooth or lower order trajectories. However, in cases where minimal sloshing is required, smooth trajectory alone is not enough, and it needs to be supplemented with explicit sloshing control strategy.

With respect to the motion path, traditionally sloshing is analyzed for one-dimensional straight motion, where the sloshing is often modeled as a simple pendulum.

In this paper, we propose the integration of the trajectory planning of seven degrees of freedom liquid container transfer robot arm and the sloshing suppression of the contained liquid. We use the Mitsubishi PA 10-7C robot arm as the experiment device. The output of the proposed method is joint trajectories, to be used as a reference of the robot motion, thus obviating the need to change the closed-loop controller. Consequently, the proposed solution is easier to be applied to different kind of systems.

Because the robot arm has spherical wrist, the motion can be conveniently decoupled into translational motion of the wrist locus and rotational motion of robot hand. This decomposition is useful in our application case, because for sloshing suppression we want to take full control of the container orientation.

For the trajectory generation of the wrist translational motion, we define the problem as a nonlinear optimization model where each joint trajectory is parameterized as cubic spline. The locations of knots are part of decision variables, thus not fixed, to allow obstacle avoidance in task space and quick motion. It is an extension to a more basic cubic spline optimization reported in our previous paper [5] in two points: motion in three-dimensional space is addressed by using multijoint robot arm, and obstacle avoidance constraints are added. As for the sloshing suppression, we use a new strategy of applying input shaping. The decoupled translational and rotational motions are each shaped by using its respective suitable input shaper and then combined as the final trajectory. We use the spherical pendulum model to simulate the response of the trajectory. In addition, a numerical sloshing simulation model is built for the purpose of examining the sloshing behavior in response to vertical motion of the liquid container in 3D space. Finally, experiments are carried out for a few example cases.

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