Trajectory Planning Method for Object Manipulation Considering Dynamic Constraint with Object

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***Abstract*— This research a method proposed of planning trajectories for the dynamic object manipulation using Rapidly-exploring Random Tree(RRT). The novelty of the method is to expand search spaces of RRT into acceleration dimensions. The proposed method solves the manipulation trajectory problem considering dynamic constraints with an object. This paper shows the effectiveness of the proposed method by a demonstration that a robot turns over a pancake.**

I. INTRODUCTION

If robots can manipulate various things in any situation, it is a step closer to the realization of life support robots. Turning over a pancake with a spatula[1] is a typical example of manipulation problem considering dynamics. However, it's not automatic planning.

In real environment, there exist some constraint conditions caused by physical contacts and sensor noises. Then, random-sampling based planning methods are developed to solve their problems[2]. Examples of such methods include Rapidly-exploring Random Tree(RRT) and Probabilistic Roadmap Method(PRM). These methods can explore the configuration space efficiently. RRT is especially effective to explore the configuration space of high dimension because RRT has high avoidance ability of local solution and no need preprocessing.

There are some previous researches of RRT. Researches [3] and [4] planned paths to move a bottle to not drop it from a tray. These researches dealt with kinodynamic constraints, although the calculation amount becomes large.

Therefore, we propose a method of planning trajectories for dynamic object manipulation with low calculation amount. Then, we show the effectiveness of the proposed method by a demonstration that a robot turns over a pancake.

II. THEORY OF MANIPULATING OBJECTS WITH DYNAMIC CONSTRAINTS

This reserch aims to plan trajectories of object operation under dynamic constraint conditions automatically. As an example of such operations, we took a task of turning over a pancake with a spatula[1]. This operation has dynamic constraint conditions. Whether the object is sliding or not is judged based on friction cone. Fig. 1 shows the conceptual diagram of friction cone. By assuming that the contact surface of the tool with the object is isotropic, the object begins to slide at the same friction angle ϕ in any direction. The apex angle of the cone is 2ϕ. By defining the contact

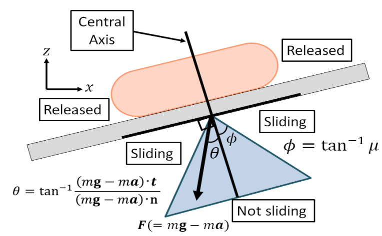

Fig. 1. Conceptual Diagram of Friction Cone

force between the object and the tool as $\boldsymbol{F}$, the object does not slide if $\boldsymbol{F}$ is in the friction cone. This condition is expressed as follows equation by using the static friction coefficient μ:

$$-\mu < \frac{(m\mathbf{g} - m\boldsymbol{a})\cdot\boldsymbol{t}}{(m\mathbf{g} - m\boldsymbol{a})\cdot\boldsymbol{n}} < \mu \quad (1)$$

Due to this, the tool giving the object acceleration that satisfy (1) in tilting the tool. Dynamic operations need to consider acceleration constraint to maintain the contact with the object.

III. RRT

When the robot moves, it is necessary to plan a trajectory considering constraint conditions to achieve the purposes. RRT is one of the random-sampling based path planning methods for searching state space randomly like a tree. This method is easy to improve to fit the intended use.

A. Expanding RRT algorithm

Conventional RRT consideres range of motion and obstacles by searching position spaces. However, they did not consider dynamic actions using the inertial force. This research deals with kinodynamic constraint conditions. We propose a method to extend search spaces to acceleration spaces.

1) Extend to acceleration spaces: Some researches dealt with kinodynamic constraint conditions[3][4] by using a method called Admissible Velocity Propagation(AVP). This method explores position and velocity spaces and store velocity information to consider dynamic constraint conditions. In contrast, our method solves this problem by searching acceleration spaces directly instead of velocity spaces. However, it can't consider the constraint conditions of range of motion. And, it needs time information in order to calculate positions from acceleration. We solve these problem in the next section.

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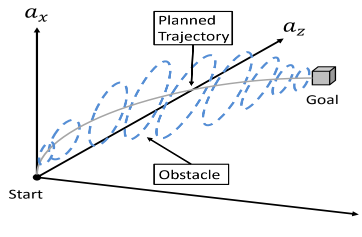

Fig. 2. Conceptual Diagram of the Proposed RRT that the State Space Consists of Acceleration Axes and a Time Axis Space

2) Extend to a time space: In order to integrate acceleration, we must consider time information. In this paper, we add another axis representing time dimension. A conceptual diagram of a state space consisting of the acceleration axes and a time axis is shown in Fig. 2. It is assumed that state space of constraint conditions spread to acceleration and time space. Turning over a pancake is reached by turning the spatula upside down. Therefore, we take into account the time information by associating the angle of the tool as $\theta = \omega t$ (here, θ indicates the angle of the tool and ω indicates the angular velocity of the tool). In addition, constraint conditions of moving range are considered by choosing angular velocity of the tool.

B. RRT Result

The proposed RRT explores the configuration space consisting of acceleration spaces and time space ($t = \theta/\omega$). Here, angular velocity of the tool was set to π rad/sec. Fig. 3 shows a generated path tree. Fig. 4 shows the trajectory calculated by integrating the path of the tree. The computation time of the proposed method was 1.97 ± 0.22sec.

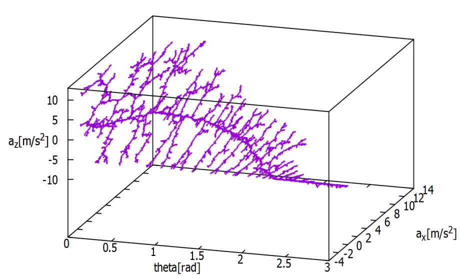

Fig. 3. Search Result

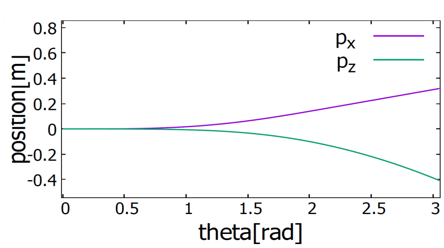

Fig. 4. Reference Position

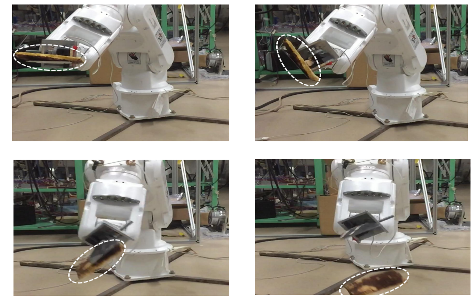

Fig. 5. Experimental Result

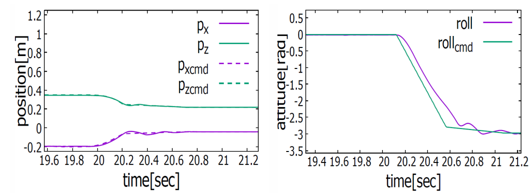

Fig. 6. Controlled Variable of the Experiment

IV. EXPERIMENT

A. Experiment Preparation

We tested our algorithm by using "MOTOMAN-MH3F," which is a six degrees of freedom manipulator supplied by Yasukawa Electric Corporation. This robot was equiped with gripper at the tip of the arm. A spatula was fixed at the gripper. We put a pancake on the spatula in advance. Measured coefficient of friction of the pancake was 1.15.

B. Results

Fig. 5 shows pictures of motion in the order of time scales and Fig. 6 shows controlled variable. These results show that the pancake was turned over correctly by the proposed method.

V. CONCLUSIONS

This paper proposed novel RRT method that explores acceleration spaces directly. The proposed method simplifies the path planning of dynamic manipulation. Then, we applied this algorithm to a task of turning over a pancake. We confirmed that search spaces consisting of acceleration axes and time axis are appropriate for dynamic object manipulation.

The future work is to improve the algorithm to specify landing position as kinematic conditions.

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