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論 文 題 目	A FEW-SHOT LEARNING APPROACH TO CONTROLLED PLANAR PUSHING OF NOVEL OBJECTS ON UNKNOWN FRICTIONAL SURFACES
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論文の内容の要旨

Robot planar pushing is one of the primitive elements of non-prehensile manipulation skills, and has been widely studied as an alternative solution to complex manipulation tasks. To transfer this skill to novel objects, reasoning the pushing effect on object motion is important for selecting proper contact locations and pushing directions. However, complex contact conditions and unknown physical properties of the object cause difficulties in reasoning. In this work, firstly, we present a new large planar pushing dataset that contains a wide range of simulated objects, and a novel representation for pushing primitives for the data-driven prediction model.

The prediction model was evaluated both in simulation and real experimental settings. The results show that the prediction model purely trained using our simulation dataset is capable of predicting real object motions accurately.

Secondly, We exploit the few-shot learning model on object center of mass estimation as well as push planning for re-arranging object positions. For center of mass estimation problem, we estimate the center of mass (CoM) of an object by narrowing down its probable location with the proposed model and Mason's voting theorem. The result shows that the CoM estimation method has good mean squared error properties and small standard deviation.

For push planning, we propose a computation efficient planning method that employs a heuristic to reduce the possibility of making sliding contact between the pusher and the object. The experimental results showed that the push planning method effectively reduces the number of pushes required to move unknown real objects to target positions.

Apart from exploiting the few-shot learning model, we proposed to use dynamic pushing to estimate the center of mass online efficiently. We conducted simulation experiment and the estimation process was conduced both in isotropic and an-isotropic frictional settings. Comparing with the result of quasi-static pushing for CoM estimation, dynamic pushing significantly outperformed both in isotropic and an-isotropic frictional setting.

In addition, we propose the Zero Moment Two Edge Pushing (ZMTEP) method to translate a novel

object without rotation to a goal pose. The proposed method enables a pusher to select the most suitable two-edge-contact configuration for a given object using the estimated CoM and the geometrical shape of the object. Notably, neither the friction between the object and its support plane nor the friction between the object and the pusher are assumed to be known. We evaluate the proposed CoM estimation and ZMTEP methods through a series of experiments in both simulation and real robotic pusher settings. The results show that the ZMTEP method significantly outperforms competitive baseline methods.

Keywords: Planar Pushing, Object Center of Mass Estimation, Path Planning, Non-prehensile Manipulation, Data-driven Automation

論文審査の結果の要旨

This dissertation addresses the problem of how to control the behavior of novel objects lying on an unknown frictional surface pushed by a robot manipulator equipped with an RGBD camera and an adjustable opening stroke parallel jaw gripper. Given that the inertial and frictional properties of the objects and floor surfaces are unknown, the ability of the robot manipulator to learn from limited data is of crucial importance for a data-driven non-prehensile manipulation algorithm in uncertain human environment. The author proposed a few-shot learning approach to predicting the effect of the pusher's contact forces on the slider's behavior and several push planning algorithms to select contact locations and pushing directions, handling the sensor noise and uncertainty. An extensive simulation study and real robot experiments under different conditions corroborate that novel objects can be moved along a controlled trajectory to a desired pose in an efficient way. The main contribution of this study is threefold: (1) a large scale, contact-rich data collection is conducted and the dataset called SimPush with more than 2 million push examples is published. (2) a novel method to encode pushes is proposed which greatly improves the model performance. Based on the encoder–decoder structure, cascaded residual attention modules are developed to combine features from different sources to deal with the push affordance prediction and compact state representation of planar pushing. (3) the most suitable pusher configuration selection methods are proposed using the estimated center of mass of the objects, leading to an efficient controlled planar pushing of novel objects undergoing pure translational motion.

To the best of our knowledge, no prior work has been done in the multi-edge contact pusher-slider interaction problem in the long history of non-prehensile manipulation. The primary novelty of this work is the ability to make a prediction about the behavior of multi-edge contacted object sliding across the frictional surface as close to the actual as possible. The proposed pushing interaction models have been valued for novelty in the robot manipulation research community and published in the prestigious IEEE Transactions on Automation Science and Engineering (Q1, IF 6.636) and Springer Intelligent Service Robotics (IF 2.468), and seven IEEE and peer-reviewed conference proceedings. The findings of this study pave the way for the development of new algorithms of learning non-prehensile manipulation skills based on fewer assumptions in cluttered human environments. This is an excellent dissertation and we approve awarding a doctoral degree to GAO Ziyan.