論文の内容の要旨

Abstract of Dissertation

Lifting of Objects with Two Mobile Robots

（2台の移動ロボットによる物体のリフティング）

劉　兆甲

Robotic lifting of objects is important because of a wide range application such as workpiece transportation in factory and arrangement in home. Lifting of objects with minimum number of mobile robots influences the efficiency of transportation and arrangement. Previously, various techniques were proposed to realize lifting of objects. However, lifting of objects with mobile robots in a minimum amount of time was not taken into account.

Mobile robots are expected to perform daily or routine domestic tasks for humans, many transportation tasks begin from object lifting; therefore, this research focuses on lifting of everyday household goods for transportation. The everyday household goods are divided into many categories by considering the shape primitive representation of the grasping part and the undulation of the bottom surface. Most of everyday household goods are the objects which (i) the shape primitive representation of the grasping part is cylinder or box, and (ii) the undulation of the bottom surface is small. Therefore, the objects which are belonging to these categories were considered in this research. The purpose is to realize lifting of objects as quickly as possible to transport them at home. Most of everyday household goods are not too heavy. They can be lifted at most two mobile robots. Therefore, an approach of lifting of objects with only two mobile robots was proposed in this research.

In order to realize lifting of everyday household goods, mobile robot mechanism, an object handling system consisting of a Gripper robot (a mobile robot equipped with a gripper) and a Lifter robot(a mobile robot equipped with a lifter), and sensor configuration are first designed by considering simple mechanism, weight distribution and enough constrained degrees of freedom. In order to realize lifting of objects with minimum number of mobile robots, a strategy for lifting of objects with the Gripper robot should be first proposed. If the object cannot be lifted by the Gripper robot, the Lifter robot should be used for cooperative grasp. It is difficult to obtain the accuracy

model of an object with sensors. Therefore, in order to know what the parameters of the object is important for lifting an object with two mobile robots, a strategy for lifting of a object with two mobile robots should be designed next. Finally, lifting of objects with the Gripper robot and lifting of objects with two mobile robots can be combined to realize lifting of objects with one or two mobile robots in a minimum amount of time. Therefore, this study is carried out in three stages.

In the first stage, the study is focused on lifting of objects by one mobile robot with a parallel-jaw gripper based on feature extraction and grasping trials.

Human always grasp an object after judging where to grasp based on the visual features of the grasping part. Therefore, features of the grasping part are important for a mobile robot to grasp an unknown object. It costs more time to obtain and process all the scanned data of an unknown object to extract the features of the grasping part for object grasping. Little information acquisition and processing can decrease the time for grasping. The inspiration comes from object grasping based on features and little information processing discussed above.

Lifting of objects in a minimal amount of time can be realized by extracting features of the grasping part from the partial shape information of the object.

Partial information regarding the shape of object is acquired by a 2D range sensor installed on the mobile robot. Three features for finding maximal contact area to generate a stable lift are extracted directly from the partial shape information of the object to determine the candidate grasping points. Three features are designed based on the following three conditions: (1) There are flat parallel surfaces or parallel tangent planes on the objects. The tangent plane passes the grasping points and it is tangent to the object surface. (2)The distance between the parallel flat surfaces or parallel tangent planes is not larger than the maximum opening width of the gripper. (3) There is no obstacle near the grasping part when a robot is lifting objects.

The object is lifted after the grasping points are detected. However, a stable lift may not be generated only using partial shape information, therefore, whether an object can be lifted by a robot is judged with a 2D range sensor after performing a lifting trial. If a lifting trial is failed, the robot will find other candidate grasping points quickly to perform lifting trials until a stable lift is generated or the object cannot be lifted by one mobile robot is known.

The proposed approach is tested with experiments. A 93.7% overall grasp success rate is sufficient to enable a robot to lift objects based on the partial shape information. We compared the proposed algorithm with 3D model construction with respect to the lifting time. The lifting time of the proposed method is only about 52.5% of that of the 3D model construction; thus, confirming the statement that the proposed method can realize lifting of an object as quickly as possible.

In the second stage, the study is focused on lifting of objects with two mobile robots by considering transition between stable states. Lifting of objects is described as a stable initial state and a stable handling state. A strategy for fast transition from a stable initial state to a stable handling state by using two mobile robots is proposed. The shape of an object is assumed to known for two mobile robots. During object lifting, the Gripper robot grasps and lifts up the object from one side. This provides a space between the object and ground that can be used by the Lifter robot. The Lifter robot moves to the insertion position and inserts the lifter into the space under the object. Finally, two robots perform circular motion at the same time, thus, the stable handling state can be realized by using the two mobile robots. Circular motion performing can be formulated as a constraint optimization problem. The goal is to realize transition from a stable initial state to a stable handling state in a minimal amount of time. Four constraints are considered for generating a stable lifting: (1) Robot motion model: The motion model of robots must be satisfied during fast transition between stable states. (2) Mechanical constraints of two mobile robots: The Gripper robot and the Lifter robot cannot tilt or slide during fast transition between stable states. (3) Relative position of two mobile robots: The center of two mobile robots should be aligned in the stable handling state to guarantee the quality of object handling. (4) Loaded state of the object: The contact point between the object and the ground should be on the lifter in the handling state. (5) No collision during transition: There should be no collisions between the object and the Lifter robot during fast transition between stable states. The penalty method and multi-start local search method were chosen to acquire optimum velocities of two mobile robots for circular motion.

Simulations are conducted for testing the effectiveness of the proposed method. From the results, it can be concluded that the proposed method results in a shorter transition time than the other two methods (GCM: The Lifter robot rotates around its center and the Gripper robot performs circular motion. LCM: The Gripper robot rotates around its center and the Lifter robot performs circular motion). The transition time of the proposed method is only about 39% of LCM.

In the proposed approach, the grasping point and lifting point are known to the robots. If the robots were controlled directly by using these points without a relative position sensing feedback, a low success rate would result. Therefore, object grasping and lifting experiments with two real mobile robots are conducted to show the efficiency of the relative position sensing feedback. A 100% success rate shows that the relative position sensing feedback guarantees that two real robots go through fast transition from a stable initial state to a stable handling state.

In the third stage, lifting of objects with one or two mobile robots in a minimum amount of time is proposed by combining both first and second stage. Lifting of objects by the Gripper robot based on feature extraction and lifting trials is used for detection of grasping points. The object is transported if it can be lifted by a single robot. Otherwise, the Lifter robot is needed. It is necessary to maximize the use of payload of a robot for guaranteeing that minimum number of mobile robots are used; therefore, the detected grasping points which a largest force applied on the gripper is selected for the Gripper robot. During the Gripper robot is moving around the object and performing lifting trails, the grasping position of the robot, the lift velocity of the lifter and whether the object is tilted or not are obtained. In generally, the lift velocity of the lifter is slower if the force applied on the gripper is larger; otherwise, the object is lifted quickly. Therefore, the detected grasping points with slowest velocity are selected for the Gripper robot.

The length of width of the object is measured using the odometry and the scanned data by considering measurement error. The proposed approach can guarantee that the object can be grasped and lifted successfully by two mobile robots even if there exist measurement error. The contact point between the object and the ground is measured by the Lifter robot for calculating the insertion position. Finally, the strategy that proposed in the second stage is used for lifting of objects with two mobile robots.

Experiments are conducted. A 89.6% overall lift success rate is accurate enough to realize lifting of objects with one or two mobile robots as quickly as possible. From the view of the lifting time, the proposed approach is especially suited for the case when the objects that can be lifted by one robot or cannot be lifted by the two robots are more than those that can be lifted by two robots.

Lifting of objects with two mobile robots in a minimum amount of time was proposed in this research. Based on the experiments, it can be verified that the proposed method is highly applicable to the real environments for lifting and transporting everyday household goods.

Future research in the lifting of objects with mobile robots includes: (1) Extended to wide range of application. (2) Extended to multiple mobile robots. (3) Extended to multiple objects.