Improved Pivot Grasping Using Friction Plane Contacts

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Abstract: *A four degree-of-freedom (DOF) robotic mechanism can be used to manipulate objects in six DOF by using a gripper altered for two-point pivot grasping where the force of gravity is used for six DOF reorientation. We show that one pivot grasp is sufficient to rotate an ashlar-shaped object from known initial stable configuration into arbitrary final stable configuration. If the initial configuration is not given, robotic vision and a series of two consecutive pivot grasps are needed to achieve the desired final configuration. Two frames of different stable configurations of the same object suffice to perform the required reorientation of the object. A pivot gripper can be further modified by replacing its contact points with rotating contact planes which improves the gripping performance and stability considerably. The effectiveness of the reorientation algorithm along with determining position and orientation of objects lying in the robot workspace with robotic vision is tested in a work cell comprising a SCARA robot and a standard industrial FireWire camera.*

Keywords: *reorientation, pivot grasp, SCARA, computer vision, point contact, plane contact*

I INTRODUCTION

An industrial pick and place application can be developed and realized using different robotic mechanisms. The choice of suitable robot and appropriate gripper [1] is determined by the characteristics of the particular task: dimensions and workspace geometry, the required accuracy and costs. In most cases the latter is the reason to search for compromise which could result in lower price. When selecting an appropriate robot, one possibility is to use a configuration without all required degrees of freedom. Such a mechanism is usually still able to reach arbitrary position but is limited in terms of orientation. The missing degrees of freedom can then be replaced by additional passive degree of freedom in order to reach the required (but not necessarily arbitrary) orientation.

II PIVOT GRASP

Rao et al. [2] show that under idealized conditions in terms of kinematics, it is possible to use a four DOF mechanism to perform the required 3D object reorientation about an axis that the robot itself does not provide, employing a single pivot grasp. Pivot grasp is defined as a two-point grasp where an object is lifted using two hard finger contacts and then pivoted into a stable configuration, exploiting the force of gravity to provide the rotation about the horizontal axis (Fig. 1).

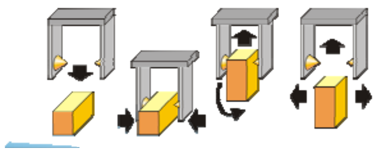

Figure 1
Pivot grasp and passive object reorientation

A pivot grasp enables a four DOF robot to move an object from arbitrary stable initial configuration into arbitrary stable final configuration, given that the following conditions are satisfied:

1 The worktable is a flat plane orthogonal to gravity vector at a known height.
2 The robot can translate the parallel-jaw gripper with three DOF and rotate it about the gravity vector.
3 The gripper has a passive degree of freedom – a pivot axis that is always parallel to the worktable.
4 The part is presented to the gripper in isolation. A sensing system (e.g., vision, light beams) determines its exact initial configuration.
5 The gripper makes two simultaneous 'hard' contacts with the part – point contacts with friction which permit rotation about the pivot axis. We assume that the part will rotate due to gravity and quickly stabilize with its center of gravity below the pivot axis.

III IMPROVED PIVOT GRASP

In theory point contact with hard fingers works perfect but proves difficult in practice. If hard fingers plunge too deep into the surface of the object, besides from damaging it, the desired rotation about the horizontal axis is compromised. Additionally, increasing the grasp force impairs the stability conditions. On the other hand, decreasing the grasp force can cause the object to slip out of the gripper due to gravity and robot acceleration. We propose an alteration to the gripper fingers in such a manner that the point contacts are replaced with round plates which are attached to the fingers using ballbearings (Fig. 2) which enable the plates to rotate freely [3].

Figure 2
Rotating plate attached to gripper finger

The modified gripper is suitable for pivot grasping if the axes of rotating plates are collinear and thereby represent the axis of the pivot grasp. The gripper is enhanced further by attaching a layer of soft rubber to each plate which increases the coefficient of friction between gripper fingers and the object.
Such a modification to the gripper replaces friction point contacts with friction plane contacts [4] which otherwise prevent any relative movement between the objects in contact but the passive degree of freedom provided by

the rotating plate enables the rotation about the contact normal axis. Given that the rotation axis is the same for both plates, the contact normal vectors are also the same which provides the system with the necessary degree of freedom to enable the rotation about the horizontal grasp axis.

In practice pivot grasping using the modified gripper works far better than grasping with hard pointed fingers, primarily because of relieved rotation conditions due to the incorporated ballbearings. On the other hand, the friction between finger plates and the object is sufficient to prevent slippage. If necessary, the grasp force can be exaggerated without impairing the ease of rotation when lifting and manipulating heavier objects or at greater manipulation speeds. In contrast to point contact, grasping employing planar contact does not compromise stability but can only increase the robustness of the grasp.

IV GRASP PLANNING

Object reorientation using pivot grasp is demonstrated in a case of manipulating standard dice such as used in e.g. gambling. The pose and the number of dots on each of the dice which are thrown arbitrarily on the robot worktable are determined using vision system with standard industrial FireWire camera [5]. The goal of the reorientation is to rotate each dice so that the surface with six dots is facing up. The system configuration is shown on Figure 3. EPSON E2S651 SCARA robot was chosen to perform the task since its accuracy and repeatability are sufficient to be neglected in comparison to the vision system in terms of achieving the desired pose successfully.

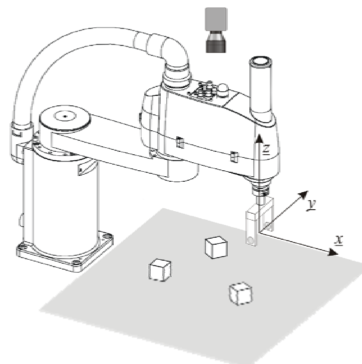

Figure 3
Robot workcell with EPSON E2S651 SCARA robot and Firewire camera

Image acquisition and processing was performed in MATLAB environment. The following steps were taken upon the acquired image in the pre-processing phase prior to object recognition:

- contrast enhancement
- noise reduction
- lens distortion elimination
- binarization
- edge detection

Black pixels (value 0) represent the background and white pixels (value 1) represent objects – the dice (Fig. 4)

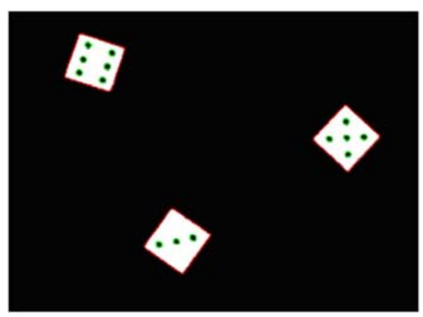

Figure 4
Dice and dots recognition using computer vision

The type of local pixel value variation in edges determines whether the edge signifies the dot border or dice border. It is used to find the number of dice and corresponding dots present on the image. Dice positions and orientations are calculated using one of the geometric methods [6]. To describe the dice poses completely in the robot reference frame, it is necessary to perform the camera-robot calibration. In our case the pseudo-inverse matrix approach was used [5].

A dice resting on the worktable can occupy six different stable configurations where the number of dots on the surface facing upwards corresponds from one to six. All the positions and orientations with the same number of dots on the upper surface of the dice represent the group of poses which are equivalent in terms of reorientation task. For each lateral dice surface four pivot grasp points are defined (Fig. 5).

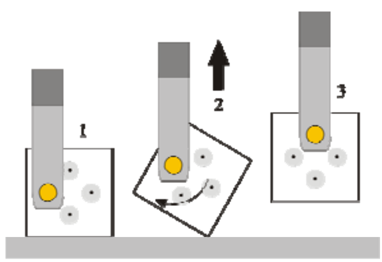

Figure 5
4 pivot grasp areas on a dice surface

When lifted, the direction of the rotation of the dice depends on the selected pivot points. The possible angles of rotation are +90°, -90° and 180°. If the dice is grasped at the highest of the four areas no rotation occurs. Given that the robot can arbitrarily rotate the gripper about its vertical axis, any pair of pivot points on lateral faces is reachable. If initial pose of the dice is known a single pivot grasp is sufficient to rotate it into any of the six possible equivalent stable configurations. However, it is not possible to determine the exact spatial orientation of the dice when it is resting on the worktable occupying one of the six stable configurations from a single image provided by the camera. In order to render it possible the following sequence of operations is carried out:

1 A snapshot of all the dice resting on the worktable is taken.
2 Dice poses along with the number of dots on the upper surface of each dice are extracted from the image.
3 All dice are rotated 90° about their horizontal axes and placed back to their initial positions using pivot grasp.
4 Another snapshot of all the dice resting on the worktable is taken. As a consequence of the action in the previous step every dice occupies spatial orientation which differs from the initial.

The information about the initial number of dots on a dice and the number of dots after the 90° reorientation about the horizontal axis is sufficient to determine its exact spatial orientation. In the final step the axis of pivot grasp which causes the dice surface with six dots to rotate upwards is determined. Table 1 shows all dot combinations before and after the 90° reorientation along with the necessary operation to rotate the six dot surfaces upwards.

Table 1
Dot combinations before and after reorientation

K	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
N_1	6	5	4	3	2	2	3	4	5	1	2	3	4	5	2	3	4	5
N_2	6	6	6	6	6	4	2	5	3	1	1	1	1	1	3	5	2	4
F	*norot*					*rot+90*				*rot180*					*rot–90*			

with rotor functions

K – combination
N1 – initial number of dots on the upper surface

N2 – number of dots on the upper surface after the 90° reorientation

d – distance traveled by the gripper from the center of the dice surface in x direction of the local coordinate frame of the gripper

F – action required to rotate the six dot surface upwards

- **norot** – no rotation of the gripper is necessary, translation of d millimeters in +z direction takes place with regard to the gripper local coordinate frame
- **rot+90** – the gripper is rotated for +90° about its vertical axis and translated d millimeters in +x direction with regard to its local coordinate frame
- **rot180** – no rotation of the gripper is necessary, translation of d millimeters in -z direction takes place with regard to the gripper local coordinate frame
- **rot-90** – the gripper is rotated for -90° about its vertical axis and translated d millimeters in +x direction with regard to its local coordinate frame

After the second image acquisition the robot gripper is moved into a neutral pose where the axis of the pivot grasp goes through the center of gravity of the dice. Should the dice be grasped and lifted from such a position no rotation would occur.

Next, one of the four operations which move the gripper with regard to N1 and N2 is performed which causes the surface with six dots to rotate upwards after grasping and lifting the dice. The proposed algorithm is effective when *d* is nonzero and shorter than half of the dice edge length. When *d* is zero (neutral position), no moment about the pivot grasp axis due to gravity occurs.

Conclusion

In the present paper pivot grasp is considered for compensating the missing degrees of freedom of robot mechanisms. The task of arbitrary dice reorientation, which would normally require a six DOF mechanism, was successfully carried out using a SCARA robot with four degrees of freedom. When the initial pose of a dice is known, a single pivot grasp is sufficient to move it from any of the six stable initial configurations to arbitrary stable final configuration. If poses of the dice are determined from an image provided by a top-mounted camera which only sees upper surfaces, it is not possible to determine their exact spatial orientations by a single acquired image. Therefore, it is necessary to perform the image acquisition twice with 90° dice reorientation about their horizontal axes in between. The latter is performed employing pivot grasping as well.

Instead of point contact with hard fingers, a plane contact combined with passive rotation was introduced. Such a modification to the gripper improves the grasping performance remarkably. In contrast to point contact grasp, a plane contact itself represents a stable configuration. In practice this allows greater initial positioning errors since they are compensated by pushing the object into a stable grasp during squeezing (Fig. 6). As a consequence, the grasp force problems typical for point contact grip are virtually eliminated. Increasing the force only contributes to greater stability of the grasp. The only persisting concern is that the grasp force is large enough to prevent the object from slipping out of the gripper during manipulation.

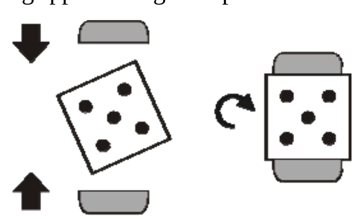

Figure 6
Object alignment during gripper closing

Increasing of the grasping force should not be exaggerated to the point of damaging the ballbearings, fingers or the gripper itself. Figure 6 shows an example of poorly determined orientation of a dice. When gripper fingers are closing, the dice falls into a stable grip naturally. When totally closed, the dice edges are perfectly parallel to the contact planes and the passive degree of freedom allows unimpeded rotation. In this way the overall robustness of the system is increased in terms of position error as well as force range. However, if the orientation error is too large it can cause the object to wedge between fingers when squeezing, without rotating it into a proper stable grasp. Wedging conditions depend mainly on the friction between the object and the fingers [7]. The robustness of the improved pivot grasp proved to be the main benefit in comparison with pivot grasp using point contacts.

The downside of the described improvement of the pivot grasp is that it is not generally applicable. It is only valid for ashlar-shaped objects while point contact pivot grasp is valid for all polyhedral objects. When applying the improved pivot grasp to a part of a different shape, the contact surface of the fingers must be designed depending on particular object geometry.

Pivot grasp vastly expands the possibilities of using a four DOF mechanism where a six DOF robot would normally be required which can reduce the costs considerably. In some industrial applications a SCARA robot combined with improved pivot grasping with sufficient robustness can represent a serious alternative to more expensive solutions.

Acknowledgements

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