Exploiting Object Symmetry for Efficient Grasping

Paper XXX

ABSTRACT

In this, paper we introduce an efficient representation for robot grasping that exploits symmetry properties of objects. The new representation forms a low-dimensional manifold, which can be used to identify the set of feasible grasps during a sequential manipulation task. We analyse the properties of this low-dimensional manifold and show that some of these properties can be used for fast manipulation planning. We apply the introduced representation and planner to bi-manual manipulation in humanoid robots.

1. INTRODUCTION

1. What is paper about?
    (a) Robots are required for assisting in collaborative tasks
    (b) Especially physical taks, e.g., domestic environments, healthcare, defense, manufacturing
    (c) Robots need manipulation and grasping capabilities (one of most important behaviors)
    (d) Grasping is at the heart of planning physical tasks
2. What is the problem?
    (a) Grasp planning taking into account environment and task constraints
    (b) Current grasp representations are based on a floating hand, which only represents the end-effector and ignores embodiment of whole robot in environment. As a result, infeasible grasps are generated and have to be pruned out in a post-processing step.
    (c) Well established algorithms assume only one action, and do not include foresight and reasoning about next actions to perform. Example, pouring into a cup. Example, putting mug into washing machine.
    (d) Motion planning with multiple subtasks -> planning needs to be fast as possible (complexity)
    (e) !Try to show that separation of planning and grasp selection is naive
    (f) Especially in bi-manual, sequential and co-worker scenarios, complexity increases
3. What is our approach?
    (a) Reoccurring patterns in the geometry of shapes can be exploited
    (b) Rotational and linear symmetries and extrusions can be exploited
    (c) In this paper we focus on rotational symmetries
    (d) Object-centered representation
    (e) Project world and hand information into the representation, thereby taking into account reachability and collisions
    (f) Examples, picture of symm. object with two hands and hands are projected into manifold.
    (g) The symmetric nature of the objects allows us to update our representation as the object rotated around the axis of symmetry.
4. Advantages of approach?
    (a) We will show that this basic property leads to a significant reduction of search complexity in grasp planning
    (b) *Since the object is symmetric any stable grasp can be rotated around the axis yielding a family of feasible grasps.*
    (c) Specifically, this property allows us to generate multiple grasps around the object which is useful for bimanual and cooperative robot hand over tasks. In addition, it allows us to plan a single grasp for a sequence of tasks.
    (d) We use this approach to generate grasps for a set of scenarios involving sequential, bimanual and collaborative components.
5. Contributions?
    (a) new representation for efficient parameterization of stable grasps
    (b) discussion of properties of representation induced by symmetric objects
    (c) a grasp planning algorithms using representation to achieve sequential and bimanual tasks

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2. RELATED WORK

3. MANIFOLD REPRESENTATIONS FOR ROTATIONALLY SYMMETRIC OBJECTS

1. Define frames L and G as local object frame and global frame
   (a) Let $\mathbf{z}$ be the axis of symmetry, $\mathbf{o}$ be the origin, and $\mathbf{a}$ be the polar axis of the object.The polar axis lies in the reference plane of the object and is perpendicular to $\mathbf{z}$. In the following, we assume that the reference plane is the base of object. Note that $\mathbf{a}$ can be arbitrarily chosen, since the object is symmetric. Using $\mathbf{z}$, $\mathbf{a}$ and their crossproduct we can form a local coordinate frame L for an object.
   (b) Any point $\mathbf{p} = [x, y, z]^T$ in the local coordinate frame L, can also be represented using a cylindrical parametrization of the coordinate system.
   (c) This parametrization leads to a point $[h, r, \theta]^T$ whose components correspond to the height, radius and angle respectively. The height is measured along the axis of symmetry $\mathbf{z}$, the radius r is the distance between $\mathbf{p}$ and $\mathbf{z}$, the angle θ is the angle between $\mathbf{a}$ and the projection of $\mathbf{p}$ onto the local reference plane of the object as can be seen in Fig. **??**.
   (d) In the following, we define the radius as a function $r(h)$ of the height, which leads to a two-dimensional parametrization $[h, \theta] \in \mathbb{S}$ of point $\vec{p}$. Subsequently, we can define the function $f : \mathbb{S} \rightarrow \mathbb{R}^3$ that maps the cylindrical coordinates to the 3D local coordinates in the following way:

$$f(\mathbf{x}) = f([h, \theta]) = [r(h)\ cos(\theta), r(h)\ sin(\theta), h] \quad (1)$$

   (e) Similarly, we can map from the 3D local coordinate space L to the surface manifold using the inverse mapping, $f^{-1} : \mathbb{R}^3 \rightarrow \mathbb{S}$:

$$f^{-1}(\mathbf{p}) = f^{-1}([x, y, z]) = [z, atan2(y, x)] \quad (2)$$

   (f) Each point can also be specified using other coordinates
   (g) This forms a cylindrical coordinate system
   (h) Difference
   (i) Which leaves us with two parameters
   (j)
   (k)
2. Low-dimensional manifold for grasps on symmetric objects
   (a) Let $\mathbf{x} \in \mathbf{S}, where \mathbf{x} = [h, \theta]^T$
   (b) h is the height of the contact point along the axis of symmetry
   (c) r

4. TASK PLANNING WITH GRASP MANIFOLDS

4.1 Planning for Task Sequences

4.2 Planning for Bi-Manual and Cooperative Tasks

5. EXPERIMENTS

6. DISCUSSION

7. CONCLUSIONS