The Capability Map: A Tool for Reasoning in Mobile Manipulation

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Fig. 1. The DLR robot *Rollin' Justin*.

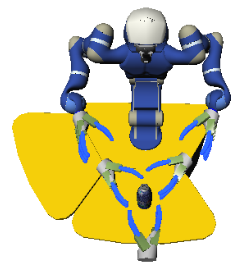

Fig. 2. Illustrates the choices to be made by the humanoid robot Justin concerning arm usage and approach direction.

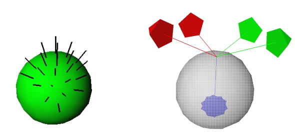

Fig. 3. An example subregion. (left) A set of reachable frames visualized as lines on a sphere. (right) Frames that correspond to a point on the sphere.

I. Introduction

Humans have at some point learned an abstraction of the capabilities of their arms. By just looking at the scene they can decide which places or objects they can easily reach and which are difficult to approach. Possessing a similar abstraction of a robot arm's capabilities in its workspace is important for grasp -, path - and task planners.

In this paper, we show that robot arm capabilities manifest themselves as directional structures specific to workspace regions. A robot arm's workspace is not uniform with respect to reachability. Instead, there are regions that can only be reached from specific directions. This directional information needs to be captured.

We introduce a representation scheme that enables to visualize and inspect the directional structures. The directional structures are captured in the form of a map, which we name the *capability map*.

The DLR robot Justin (1) is a humanoid upper body with 42 degrees of freedom (DOF). It has two redundant arms with 7 DOF each. Using Justin, we want to grasp and manipulate objects using both arms. To decide when to use which arm, we need to be able to evaluate which arm can e.g. best grasp certain objects in the task space (figure 2). Considering a mobile manipulator the question arises how best to position the mobile platform to have optimal manipulation capabilities with respect to the operating area, e.g. a table.

In general, we propose a representation of a manipulator's capabilities that can be used to characterize which places are easily reached. Structure inherent to the robot arm's capabilities inside its workspace is easy to recognize. Using this representation the manipulator is able to choose good approach directions and positions for handling objects.

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II. The capability map: Representation of kinematic capabilities

This section summarizes the basic ideas behind the method to represent the reachable workspace of a robot arm, as introduced by Zacharias et al. The key point that distinguishes this model from other methods that characterize the reachable workspace is that both position and orientation information is encapsulated. The proposed model, called the *reachability map* of the robot arm, represents its discretized workspace. For each subregion the reachability of a set of representative frames is examined and recorded. A frame here specifies the position and orientation of the end-effector coordinate system with respect to the reference system of the subregion. Fig. II (left) shows a set of reachable frames visualized as lines on a sphere. Fig. II (right) shows two exemplar frames corresponding to one of the points on the sphere. The aggregation of these discretized and examined subregions of the workspace builds the reachability map. It is computed for each robot arm offline. The map is only build once and can then be consulted to determine which regions are reachable from which direction. Fig. 4 shows a visualization of the reachability map for the right robot arm of Justin. The color encodes the reachability index. This index measures how well a region is reachable, i.e. how many frames are

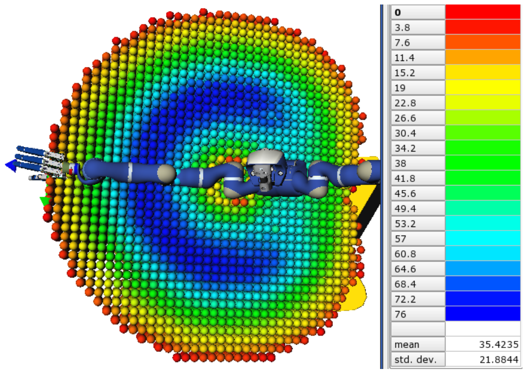


Fig. 4. Shows the reachability spheres across the workspace. The workspace representation was cut for better visibility of the structure.

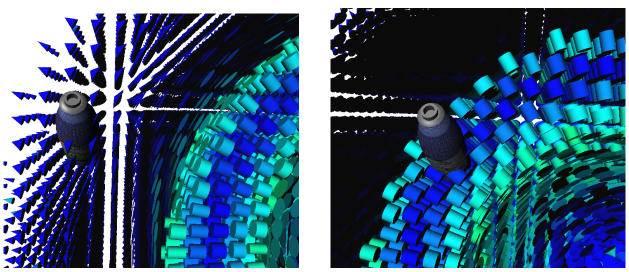


Fig. 5. A bottle in different areas of the workspace.

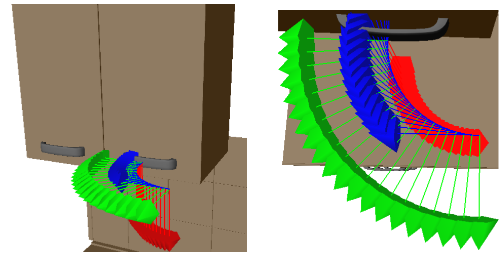
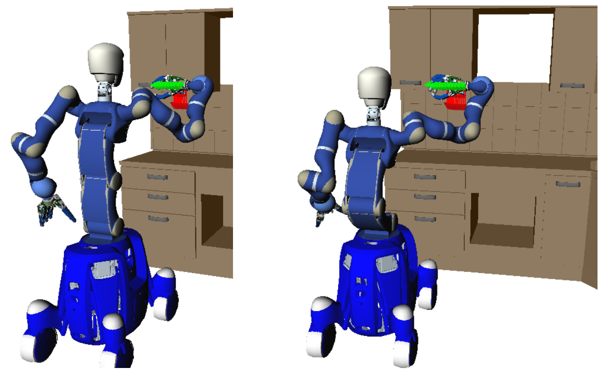


Fig. 6. (Left) Trajectory for opening a closet. (Right) A zoomed view.



(a) (b)

Fig. 7. Rollin' Justin is placed to open a closet. (a) The torso is in configuration C1. (b) The torso is in configuration C2.

reachable for this region. Red denotes the minimum value and blue denotes the maximum value. Although this scalar representation is a directionless index, that is not informative from which direction the region can be reached, it relates to from how many directions the region can be reached and therefore gives an impression of the capabilities of the robot arm in its workspace. The data indicating which of the individual frames is reachable is also available and is used in the analysis.

III. Applications

A. Positioning to grasp an object

Using the capability map, it can easily be determined whether an object of the scene is reachable and from which directions. Fig. 5 (left) shows a bottle placed near the outer border of the workspace. In this region cones are used to represent the directions from which the areas can be reached. Fig. 5 (right) shows the same bottle placed at the center of the robot arm workspace. Here cylinders are predominantly used to capture the reachability data. Therefore the possibilities to approach and manipulate the object are more numerous as is directly evident from the capability map. A grasp planner with the capability map as a model of the robot arm's reachable workspace can use this model to predict the reachability of a grasp. With regard to positioning a mobile manipulator the capability map can be used to determine whether an object is currently reachable or how the robot must be positioned to allow manipulation.

B. Positioning for constraint manipulation

We use the example of opening a closet as an example. If a closet has to be opened, the end-effector grasps the handle and moves on an arc (Fig. 6). We assume the trajectory template followed by the robot arm TCP to be given as a sampled sequence of frames with respect to a local reference system. The frames are mapped to their discrete representations in the capability map forming a search pattern. The search pattern is localized in the capability map using correlation and then validated. A set of solutions is computed, and deriving the corresponding mobile manipulator position is straight forward (Fig.7).

IV. Acknowledgments

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