Path Configuration for Abstractly Represented Tasks with Respect to Efficient Control

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***Abstract*— A robotic manipulation system that is supposed to replace a human operator needs to deal with a variety of possible manipulation actions. These actions may be more or less constrained in their motion profile and in the accuracy of the transport goals. Some of this variation can be used to simplify the control and to optimize the base placement to improve the efficiency of the generated motion. We present an analysis tool that uses the abstraction of the human actions to generate path with efficient motion profiles.**

We compare the dynamics of a robot for different paths. We show in experiments that certain path properties are preferred to support efficient control and that the intuitive solution does not necessarily agree with the results optimizing for efficiency.

A. Motivation

Abstractly represented tasks can be described by its characteristic properties. These properties have to be considered during path planning. Moreover, the path should be collision free, what can further reduce the number of possible paths. A lot of different paths can remain as solutions nevertheless. Of course, it is desirable to select the most efficient one to save energy and to reduce the strain on the hardware. Furthermore, an easy and efficient control is desirable. Consequently, each joint of the robot should move slowly and smoothly. Abrupt and fast changes in joint speed should be avoided. But how should the path look like to support efficient dynamics?

We want to evaluate paths with respect to the efficiency of dynamics for a given robot. Which modifications of the path influence the robot's dynamics? How can we make use of the freedom in path planning, which comes along with the abstract representation of tasks?

B. Method

The paths, which we want to compare, can be distinguished between the following three categories:

- **basic motion shape** - Four different basic motion shapes (bs) are considered here: a *line (bs 1)*, a *half circle (bs 2)*, a *wiggly line (bs 3)* and a *half quadrilateral (bs 4)*. The latter three are positioned upright over basic motion shape 1 along the vertical axis in the room (see Fig. 1).
- **compression and elongation** - The basic motion shapes 2-4 can be compressed or elongated by a factor e along the vertical axis in the room.
- **bias** - The basic motion shapes 2-4 of the path can be biased. The path is, then, turned around the axis of basic motion shape 1 by an angle β.

This work was supported by a cooperation with the German Aerospace Center (DLR).

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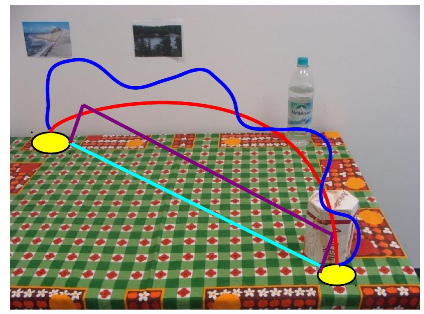

Fig. 1. Paths with different properties (e.g., motion shapes) are shown for a manipulation between two areas (yellow). Which path should be chosen to achieve efficient control during the manipulation?

The robot's dynamic properties for a certain path can depend on the placement of its base. Therefore, we process the evaluation for different positions of the base.

C. Experiments

We perform experiments on different scenes with a 3-DoF robot with three rotational joints. We use the concept of Functionality Maps as abstract representation of a task [1]. The map consists of Location Areas, which are the characteristic areas, where manipulations can start or end. Here, we are interested in the evaluation of paths, which can be used for a manipulation between two Location Areas.

We evaluate simulated and real world data in our scenarios. We use simulated scenes for the first scenario A and real scenes for the second scenario B. Scene I in scenario A has two Location Areas on a table. Scene II consists of three Location Areas, which are placed on the corners of a quadrilateral. In scenario B, we use the Location Areas, determined in [1] (illustrated in Fig. 2).

The position of the robot's base is varied on circles and rectangles, which are spanned up around the mean of all Location Areas. The circles and rectangles have three different sizes and three different heights (see, e.g., black circles and rectangles in Fig. 5). We choose six equally distributed points on each circle and eight points on each rectangle.

D. Results

We analyze the properties of the 100 best results for each scene. The best results are defined as paths, for which the

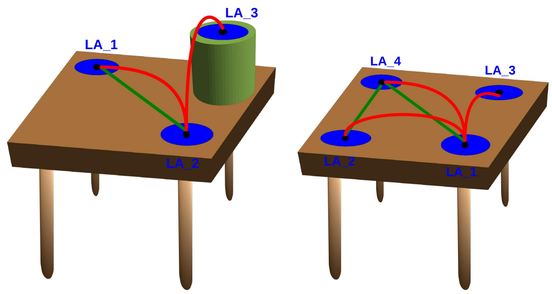

Fig. 2. Fig. 4. Scene I (left) and II (right) in scenario B: The lines/ curves between the blue Location Areas (LA) refer to the original paths of lifted objects (red) and paths of pushed objects (green).

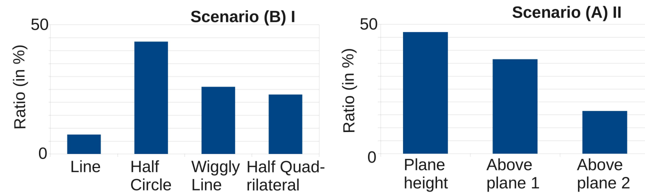

Fig. 3. *Left:* Exemplary ratio of each basic motion shape (among the 100 best results). *Right:* Exemplary ratio of height of the robot's base. "Plane height" is the height at the table plane. "Above plane x" refers to a height "x" above the table. The higher "x", the further away the height from the table.

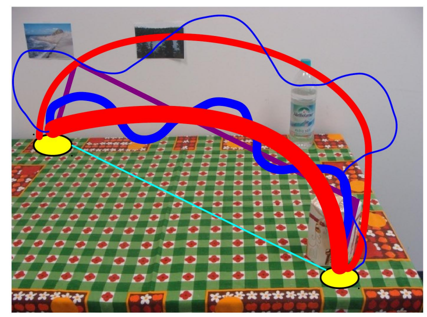

Fig. 4. Illustration of the preferable basic motion shapes and compression/ elongation factors among all scenarios: The thicker a line/ curve, the higher its preference. As it can be seen, the half circle is the most favorite motion shape. Moreover, it is visible, that a small compression/ elongation factor is preferred.

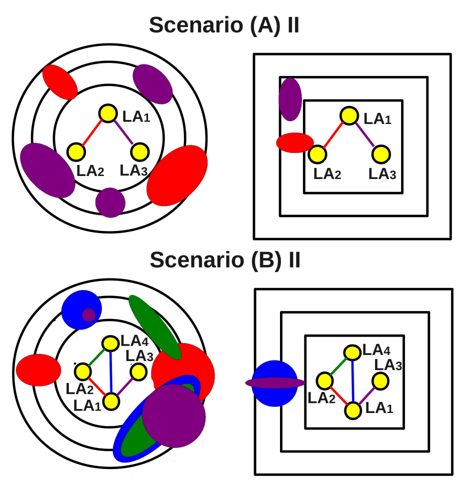

Fig. 5. Exemplary preferred positions of the robot's base in relation to the Location Areas (LA). The color of the preferred regions (red, magenta, blue and green circles, resp., ellipsoids) for the robot's base refers to the corresponding path in the same color.

maximally required joint speeds are the lowest. The maximal change of the joint speed is very small in all scenes of the 100 best results (below $7 \cdot 10^{-5}$ rad/s; average joint speed for comparison: 0.004 - 0.038 rad/s). Therefore, the maximal change is not included in the definition of the best results. In general, we just evaluate paths, which can be reached by the manipulator (within a tolerance of 50 mm). Fig. 3 (left) shows the ratio of each basic motion shape in scenario B, Scene I. It is surprising, that a line, which is the shortest connection between two points, is hardly among the best results in the scenarios. The line seems to be a demanding motion shape. Even the wiggly line and the half quadrilateral are significantly more often among the 100 best results than the straight line. The half circle is the most favorite motion shape. The results of the other scenes look similar. In general, compressed paths are preferred, which lead to relatively short connections (compression/ elongation factor $e = 0.5$ in 80% of the best 100 results). At first, this seems to be quite logical. However, the line (the shortest connection) is hardly among the best 100 results. Fig. 4 illustrates the most favorite motion shapes and compression/ elongation factors of the paths in general.

The bias seems to be used as a fine adaption of the distance between the base and the desired points of the end-effector. The path can be "pushed away" or "pulled" towards the robot's base, in order to enable more efficient dynamics.

An additional result of our work are the preferable areas of the robot's base with respect to efficient dynamics. Most of them are on the side of the desired path at table height. A base placement at table height is preferred in three out of four scenes (see, e.g., Fig. 3, right). Just in scenario A, Scene I, the base positions of the 100 best results are approximately equally distributed among the three different heights. The height of the base does not seem to influence the efficiency of dynamics in this scene. Fig. 5 shows, that base positions on the side of the desired path are preferred. It is interesting to see, that the base positions on the rectangles are hardly among the 100 best results.

E. Conclusion

Our experiments show, that the path properties influence the dynamics in a partly unexpected manner. Therefore, it is worth to further analyze the path properties with respect to efficient control in future work.

References

[1] S. Petsch and D. Burschka, "Representation of manipulation-relevant object properties and actions for surprise-driven exploration," in *IEEE/RSJ International Conference on Intelligent Robots and Systems*, San Francisco, California, USA, 2011, pp. 1221–1227.