

# End-Effector Mobility for Manipulators in Confined Spaces

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**Abstract**—A robotic manipulator operating within a confined space ideally positions its end-effector with minimal spatial displacement of each link. Achieving certain poses can require a large overall displacement of the hardware. This work investigates the effect of an additional degree of freedom (DOF) at the end-effector of a KUKA LBR iiwa14 arm by assessing the space occupied by the arm during 6 manipulation tasks and the dexterity of the arm within its workspace.

**Index Terms**—Dexterous Manipulators, Path Planning, Workspace Analysis, Constrained Motion

## I. INTRODUCTION

While a commercial robotic arm can reach many poses when operating in free space, the path required to reach these poses can require a large motion of its links, especially when attempting a change in end-effector orientation [1]. This large motion could be problematic when operating in confined spaces, for example, when picking an item from within a cluttered cupboard. Although the required pose to pick the item may be achievable by the arm, the path the arm must travel through to reach that pose could be blocked by the cupboard walls or other items on the shelf. Existing robotic kitchen systems [2] are able to cook pre-defined recipes when operating within a standardised environment. However, most domestic spaces are optimised for the robot workspace. Previous studies have been performed implementing a robotic arm for domestic use within cluttered environments which found difficulty in successfully achieving grasp poses [1] [3]. Performance could be improved by minimising the motion required of the robotic arm when positioning the end-effector, in order to lower the occurrence of object collision. To achieve this, additional DoF could be provided in the end-effector of the kinematic chain [4] [5]. This paper investigates the impact of an additional revolute joint at the wrist of the end-effector when carrying out a series of tasks within a restricted workspace. Herein, we simulate an additional joint at the interface between a KUKA LBR iiwa14 7DoF robotic arm [6], Fig. 1 and a Franka Emika parallel gripper [7].

## II. METHODOLOGY

The analysis is performed by simulating the arm in two kinematic configurations, for comparison. First, with a rigid link between the arm and the gripper and, subsequently, with

This work was supported by EPSRC EP/S021795/1.

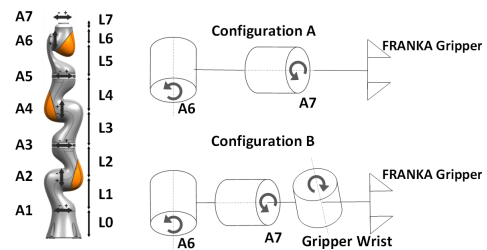


Fig. 1. Left: KUKA robot joint axis (A) and links (L) [6], Right Top: Fixed Gripper Configuration A, Right Bottom: Mobile Gripper Configuration B

an additional revolute joint (the gripper’s wrist) positioned between the arm and the gripper, as shown in Fig. 1. The arm model is the IIWA STACK metapackage [8] which has been simulated in Gazebo [9], controlled using ROS [10] and MoveIt! [11]. The added gripper wrist joint has a range of  $-90^\circ$  to  $+90^\circ$ , with its axis of rotation perpendicular to KUKA axes A6 and A7. This provides a 3-axis rotation at the end-effector. No model mesh has been created for this joint; as a simplification, it is assumed that the gripper is attached directly to the final joint of the KUKA arm (A7) without interfacing hardware, meaning that no additional length is considered at the interface in either configuration A or B, Fig. 1. Two experiments have been explored regarding the impact of the gripper’s added wrist joint on: a) the spatial displacement of the arm’s links (manipulation task) and b) the workspace of the arm when planning Cartesian motion (path planning task). The arm is controlled in end-effector space and the joint angles are found by MoveIt! default kinematics solver KDL.

### A. Manipulation Task

The spatial displacement of the arm has been analysed for 6 object manipulation tasks: 2 pick-rotate-and-place tasks (rotates as it moves), 1 pick-and-pour task (rotate about an edge) and 3 wrenching tasks (rotate about a centre point). For each task, the end-effector follows the same path in both the fixed (A) and mobile (B) gripper configurations. During motion, the centre line of each link of the arm sweeps out a surface, Fig. 2. The area of this surface is calculated for each task. In comparing the two configurations, a smaller total swept area indicates a more effective motion.

### B. Path Planning Task

The workspace is sampled at 10cm intervals within the  $+X+Y+Z$  quadrant for a total of 1400 goal positions. The arm

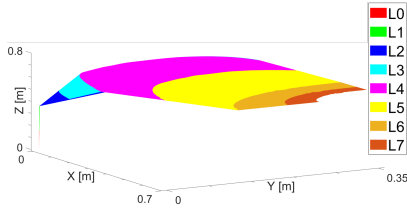


Fig. 2. Surface swept by each robot link, L, during a wrenching motion

is commanded to place the end-effector at each position in six different orientations to give a total of 8400 goal poses. The ability to plan a simple point to point straight line path from an arbitrary start pose to each of these goal poses is assessed in both the fixed (A) and mobile (B) gripper configurations. The start pose is arbitrarily selected:  $A1=20^\circ$ ,  $A2=20^\circ$ ,  $A3=0^\circ$ ,  $A4=-40^\circ$ ,  $A5=0^\circ$ ,  $A6=70^\circ$ ,  $A7=0^\circ$ , Gripper Wrist Joint= $0^\circ$ . To validate the sampling interval, the workspace is sampled at 1cm intervals for one orientation. This showed similar (success rate to within 0.5%) results to 10cm sampling for the same orientation. For computational efficiency, the interval of 10cm is then used for all poses.

### III. RESULTS

Table I presents the results of the manipulation task. The total area of the surfaces swept by the links of the KUKA arm are presented for each of the six object manipulation tasks. Although the impact of the gripper's added wrist joint was low for the pick, rotate and place tasks (a reduction in swept area of  $<10\%$ ) the optimisation achieved for the wrenching tasks, where the object is rotated about its centre point, was much more substantial ( $>50\%$ ). This suggests that for changes in end-effector orientation occurring over smaller distances, the optimisation of movement is more significant than for movements occurring over larger distances. Table II presents the results of the path planning task. The number of positions successfully reached by the Cartesian point-to-point planner is shown according to the number of orientations successfully reached at each position. Whilst the added wrist joint has low impact on the number of positions reached in at least 1 orientation (improved from 64% to 68% of the workspace sampled), it has impacted the end-effector dexterity at those positions. With the added wrist, 42% of the sampled workspace positions are reached in at least 4 orientations and 23% are reached in all 6 orientations. Without the wrist, no points in the workspace are reached in 5 or 6 orientations and only 4% are reached in 4 orientations.

TABLE I  
MANIPULATION TASK RESULTS

Motion	Total Swept Area [m <sup>2</sup> ]		Mobile Gripper Swept Area Reduction
	Fixed Gripper	Mobile Gripper	
Pick, Rotate in X and Place	0.29	0.27	6.8%
Pick, Rotate in Y and Place	0.31	0.28	7.6%
Pick and Pour	0.24	0.21	14.3%
Wrench about X	0.21	0.10	50.1%
Wrench about Y	0.35	0.17	52.4%
Wrench about Z	0.33	0.13	60.8%

TABLE II  
PATH PLANNING TASK RESULTS

Orientations Reached	Fixed Gripper Configuration		Mobile Gripper Configuration	
	Positions achieved	% of sampled workspace	Positions achieved	% of sampled workspace
At least 1	895	64	956	68
At least 2	605	43	822	59
At least 3	349	25	717	51
At least 4	60	4	582	42
At least 5	0	0	473	34
All 6	0	0	319	23

### IV. CONCLUSION

The addition of a single degree of freedom at the end-effector reduces the space occupied by the robot arm and improves point-to-point path planning success for motions where a large change in orientation occurs over a smaller distance. Reduced improvement is shown for motions with a smaller change in orientation or where the orientation change occurs during motion over a longer path. Within a confined space however, it is more likely to be necessary to maneuver over small distances and to need to perform larger orientation changes. The added wrist joint allows the goal pose to be achieved whilst minimising the spatial displacement of the preceding links of the robot arm.

This work is a preliminary investigation into the potential improvement in performance achievable with a robot arm of increased end-effector mobility. Future work will account for the interfacing hardware and design of the wrist joint. Although this experiment has been performed using a specific commercial robot arm and gripper, it is expected that the findings would be applicable to all similar setups.

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