Styles, K. L., Scott , T. B., & Tzemanaki, A. (2021). End-Effector Mobility for Manipulators in Confined Spaces. In *UKRAS21 Conference: “Robotics at home” Proceedings, 2nd June 2021* (pp. 37-38) https://doi.org/10.31256/Ut2Qg2T

# End-Effector Mobility for Manipulators in Confined Spaces


Kathryn Styles Wood
*Bristol Robotics Laboratory*
*University of Bristol, UK*
kat.styles@bristol.ac.uk

Thomas B. Scott
*Interface Analysis Centre*
*University of Bristol, UK*
T.B.Scott@bristol.ac.uk

Antonia Tzemanaki
*Bristol Robotics Laboratory*
*University of Bristol, UK*
antonia.tzemanaki@bristol.ac.uk



***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.


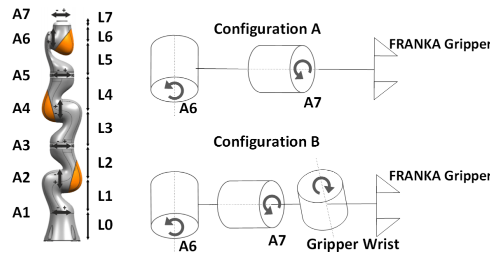


Fig. 1. Left: KUKA robot joint axis (A) and links (L) [6], Right Top: Fixed Gripper Configuration A, Right Bottom: Mobile Gripper Configuration B

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° to +90°, 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 Movit! 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

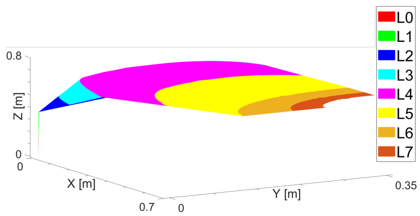


Fig. 2. Surface swept by each robot link, L, during a wrenching motion

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°, A2=20°, A3=0°, A4=-40°, A5=0°, A6=70°, A7=0°, Gripper Wrist Joint=0°. 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 it's 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$^2$]** | | **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.

## References

[1] W. Ruotolo, R. Thomasson, J. Herrera, A. Gruebele and M. Cutkosky, "Distal Hyperextension Is Handy: High Range of Motion in Cluttered Environments," IEEE Robotics and Automation Letters, vol. 5, no. 2, pp. 921-928.

[2] Moley Robotics, 'The world's first robotic kitchen'. [Online]. Available: https://moley.com/. [Accessed:19/03/2021].

[3] D. Wang, C. Kohler A. ten Pas, M. Liu, H. A. Yanco and R. Platt Jr, "A Scooter-Mounted Robot Arm to Assist with Activities of Daily Life," CoRR, vol. abs/1809.09541, 2018.

[4] R. R. Ma and A. M. Dollar, "On dexterity and dexterous manipulation," 2011 15th International Conference on Advanced Robotics (ICAR), Tallinn, Estonia, 2011, pp. 1-7.

[5] F. Negrello, S. Mghames, G. Grioli, M. Garabini and M. G. Catalano, "A Compact Soft Articulated Parallel Wrist for Grasping in Narrow Spaces," IEEE Robotics and Automation Letters, vol. 4, no. 4, pp. 3161-3168.

[6] KUKA Roboter GmbH, 'LBR iiwa LBR iiwa 7 R800, LBR iiwa 14 R820 Specification'. [Online]. Available: http://www.oir.caltech.edu/twiki_oir/pub/Palomar/ZTF/KUKARoboticArmMaterial/Spez_LBR_iiwa_en.pdf. [Accessed:19/03/2021].

[7] FRANKA EMIKA, 'Introducing the Franka Emika Robot'. [Online]. Available: https://www.franka.de/. [Accessed:19/03/2021]. [Accessed:19/03/2021].

[8] C. Hennersperger, B. Fuerst, S. Virgaand, O. Zettinig, B. Frisch, T. Neff, and N. Navab, "Towards MRI-based autonomous robotic US acquisitions: a first feasibility study," IEEE Transactions on Medical Imaging, vol. 36, no. 2, pp. 538-548, Feb. 2017.

[9] N. Koenig and A. Howard, "Design and use paradigms for Gazebo, an open-source multi-robot simulator," 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) (IEEE Cat. No.04CH37566), Sendai, Japan, 2004, pp. 2149-2154 vol.3.

[10] Stanford Artificial Intelligence Laboratory, 'Robotic Operating System'. (ROS Noetic) [Online]. Available:https://www.ros.org. [Accessed:19/03/2021].

[11] I. A. Sucan and S. Chitta, 'MoveIt', [Online] Available:moveit.ros.org. [Accessed:19/03/2021].