Automatic extraction of a task frame from human demonstrations for controlling robotic contact tasks

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1 Introduction

In the context of robotics, contact tasks include the manipulation of objects to achieve task goals by controlling both the motion of the objects and the contact wrench (force and moment) between them. Designing a controller for such tasks is challenging. Typically, an expert selects a suitable coordinate system, referred to as the task frame, to design a control strategy and accomplish the task goals. However, this study introduces a novel data-driven approach, automating the extraction of an optimal task frame from human demonstrations.

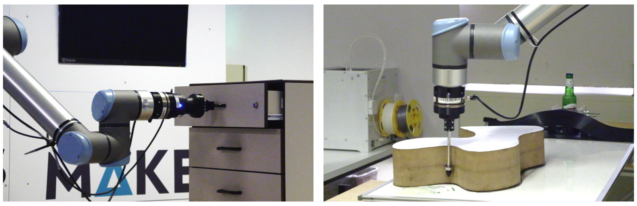
2 Task frame extraction

The demonstrated motion and wrench data are analyzed to extract the task frame. The proposed approach yields an origin and an orientation for the task frame according to uncertainty criteria recognized from the data. This approach is rooted in screw theory. To illustrate the effectiveness of selecting a suitable task frame, a non-task-specific constraint-based control strategy is developed which is capable of successfully performing diverse tasks.

Origin Selection: The demonstrated motion and wrench data can be represented by screws. An appropriate origin of the task frame should maximize decoupling between directional and moment components of the screw. In other words, it should decouple rotation and translation in the motion domain, and analogously, force and moment in the wrench domain. To explore this idea, we create models that achieve perfect decoupling and test them on the motion and wrench data, generating various candidates. Using uncertainty criteria, as explained in [1], we either select or combine these candidates to identify an optimal origin for the task frame.

Orientation Selection: An appropriate orientation of the task frame should maximize decoupling between motion and wrench control along each axis. Applying singular value decomposition to the motion and wrench data reveals the principal directions of variation. These candidates are then combined using uncertainty criteria, leading to the identification of an optimal task frame orientation.

Control Strategy: With the extracted task frame, we can now express the motion and wrench data within it and decide about the desired signals. While various types of controllers can be implemented to follow the desired signals, we designed a constraint-based controller [2] which introduces impedance behaviors to follow the desired signals.



(a) (b)

Figure 1: Drawer opening and 2-D contour following tasks performed by a UR10e robot.

3 Results

To validate the proposed approach, it was applied to a diverse set of applications, including both daily-life tasks like drawer opening (Figure 1-a) and technical tasks such as 2-D contour following (Figure 1-b). The proposed approach yielded promising results by successfully extracting a task frame which aligned with the expert's choice, all accomplished without the necessity for any hyperparameters. For instance, in the case of 2-D contour following, the origin and orientation of the extracted task frame deviated from the expert's choice by 8.5° and 2 mm, respectively. Additionally, the approach has the capability to recommend an effective non-task-specific control strategy.

References

[1] A. Ancillao, M. Vochten, A. Verduyn, J. De Schutter, and E. Aertbeliën, "An optimal method for calculating an average screw axis for a joint, with improved sensitivity to noise and providing an analysis of the dispersion of the instantaneous axes," PLOS ONE, 2022.

[2] E. Aertbeliën, and J. De Schutter, "eTaSL/eTC: A constraint-based task specification language and robot controller using expression graphs," IEEE/RSJ International Conference on Intelligent Robots and Systems, 2014.

Acknowledgment This work was supported by the European Research Council (Grant No. 788298).