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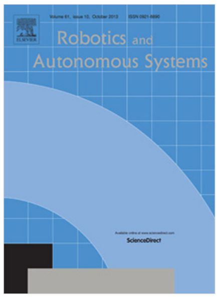

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Force-based Variable Impedance Learning for Robotic Manipulation

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Abstract

In order for robots to successfully carry out manipulation tasks, they require to exploit contact forces and variable impedance control. The conditions of such type of robotic tasks may significantly vary in dynamic environments, which demand robots to be endowed with adaptation capabilities. This can be achieved through learning methods that allow the robot not only to model a manipulation task but also to adapt to unseen situations. In this context, this paper proposes a learning-from-demonstration framework that integrates force sensing and variable impedance control to learn force-based variable stiffness skills. The proposed approach estimates full stiffness matrices from human demonstrations, which are then used along with the sensed forces to encode a probabilistic model of the task. This model is used to retrieve a time-varying stiffness profile that allows the robot to satisfactorily react to new task conditions. The proposed framework evaluates two different stiffness representations: Cholesky decomposition and a Riemannian manifold approach. We validate the proposed framework in simulation using 2D and 7D systems and a couple of real scenarios.

Keywords: Learning from demonstration, Variable impedance, Robot learning, Robotic manipulation

1. Introduction

Day by day robotic applications are bringing robots into unstructured environments (e.g., houses, hospitals, museums, etc.) where they are expected to perform complex manipulation tasks that are hard to program. This difficulty arises mainly because unstructured environments are dynamic, uncertain, and possibly inhabited by humans, therefore making hard-coding an unfeasible approach. Moreover, as manipulation tasks require contact with the environment (and possible humans), it is imperative to use complaint motions, which further increase the complexity of programming. In this context, human expertise can be alternatively exploited in a robot learning approach, where the robot learns, from human examples, to reproduce force-based manipulation tasks that require variable impedance.

In this vein, Learning from Demonstration (LfD) [1] is a user-friendly and intuitive methodology for non-roboticists to teach a new task to a robot. In this case, task-relevant information is extracted from several demonstrations. Standard LfD approaches have focused on trajectory-following tasks, however, recent developments have extended robot learning capabilities to the force and impedance domains [2, 3].

In this paper, we propose to exploit LfD to learn manipulation tasks that demand to use different stiffness levels according to the state of the environment and the task itself, which are substantially related to the robot force-based perceptions. Specifically, the proposed learning framework implements kinesthetic teaching (Fig. 1-*left*) to collect demonstrations of a manipulation task, where both kinematic and dynamic data are recorded.

Figure 1: *Left*: a human operator teaches a robot how to perform a valve-turning task. *Right*: a snapshot showing the valve-turning task reproduced by a KUKA LWR robot.

The demonstrations along with a virtual model of a spring-damper system are used to obtain time-varying stiffness estimates (Section 3.1). These are computed as the closest symmetric positive semi-definite stiffness matrix of a least-squares estimation (Section 3.3). Such estimates are subsequently used as the desired stiffness for corresponding force patterns observed during the demonstration phase. Both sensed forces and estimated stiffnesses are then probabilistically encoded using a Gaussian mixture model (GMM), which is exploited during reproduction phase to retrieve variable stiffness profiles by Gaussian mixture regression (GMR) (see Sections 4 and 5 for details)[1]. In summary, the main contributions of our LfD framework are:

– Exploitation of force sensing and variable impedance control to learn and reproduce manipulation tasks requiring different stiffness levels.

[1] We refer to variable impedance learning as the process of estimating and reproducing variable stiffness profiles. Nevertheless, the proposed approach can also be used to learn variable damping controllers.

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