Programming by Demonstration for Shared Control
with an Application in Teleoperation

This post provides an overview of our paper Programming by Demonstration for
Shared Control with an Application in Teleoperation by Martijn Zeestraten, Ioannis
Havoutis and Sylvain Calinon, that is published at the IEEE Robotics and Automation
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1 Overview

Teleoperation has been a key drive for robotics research as many tasks need to be
performed remotely. These tasks occur in a broad application domain, ranging from
deep sea to outer space, and are typical in environments that are dangerous and/or hard
to reach. Traditionally, during teleoperation, the robot motion is directly controlled by
the operator. In such systems, the performance of the operator can be improved by
increasing the transparency of the teleoperation system, and by providing her with a
feeling of presence.

2 Shared Control

Shared control strategies can improve task performance in teleoperation. In such sys-
tems, automation guides or corrects a human operator. The amount of correction or
guidance that is provided is denoted the level of automation. As the variety of teleop-
eration tasks is large, manually specifying the underlying automation is time consuming.
In this work, we presented an approach to program (learn) this automated system by
demonstration. Our approach determines the level of automation online, by combining
the confidence of automation and teleoperator.

2.1 Riemannian Representation

The methods presented here involve control and statistical encoding of end-effector
poses as elements of a Riemannian manifold. Riemannian manifolds are not generally
Euclidean, and common approaches for control and statistics cannot be directly applied
to Riemannian data. We present particular implementations of our approach for haptic
shared control (HSC) and state shared control (SSC).

2.1.1 State Shared Control

SSC combines the inputs after the interface on which the human operates.
2.1.2 Haptic Shared Control

HSC combines the inputs at the user interface. The input of the agent is conveyed to the human agent through forces applied at the user interface.

![Block diagrams of the shared control strategies considered.](image)

Figure 1: Block diagrams of the shared control strategies considered.

3 Scenario

The Large Hadron Collider (LHC) at CERN in Switzerland is a hazardous environment. Radiation inside the LHC poses a health threat to maintenance personnel. Currently, maintenance schedules include a period to allow radiation to decay and create a safe working environment. Teleoperation can reduce downtime due to maintenance, as it removes the decay period from the maintenance schedule. The experimental task is part of the maintenance procedure of a collimator—a device used to parallelize particle beams. The LHC can contain up to 152 collimators, which are located in radioactive areas. This maintenance procedure involves the removal and replacement of a protection cover. Removal of the cover is achieved by sequentially moving towards it, grasping it, unlocking it using a 10 degree clockwise rotation, and sliding it from the locking pins.

![Experimental setup and task.](image)

Figure 2: Experimental setup and task.

The experimental setup consists of two Barrett WAM 7-DOF robots and a 1:1 mock-up of the collimator. The left WAM acts as the master device, and is equipped with a haptic ball that allows the teleoperator to control the end-effector pose of the slave.
The WAM pictured on the right acts as the slave and is equipped with a three fingered hand (Barrett BH8-280). The hand is programmed to have two states (pre-grasp, and grasp) which are activated by the operator. The mock-up of the collimator contains all parts required for this particular maintenance scenario.

Figure 3: Visualization of the trained skill on the collimator. The bound of the yellow ellipsoid indicates one standard deviation of the position covariance. The ellipsoid center indicates the mean. The orthogonal colored lines indicate the mean orientation. The colored ellipsoids at the end of each axis indicate 4 standard deviation of the rotational covariance.

The virtual fixture is programmed (learned) through kinesthetic teaching; we collect data while manually moving the robot to perform the maintenance operation. Although kinesthetic teaching cannot be applied on site, it can be used in a safe environment prior to the execution of the teleoperation task. Alternatively, one could use demonstration data of an expert teleoperator.

We demonstrated a number of successful removal and replacing attempts of the cap. For each demonstration we recorded position and orientation of the robot end-effector and the collimator. To allow the transfer of the demonstrated skill to different poses of the collimator, we project the recorded end-effector poses in the collimator frame, i.e. the collimator pose represents the task context.

4 Outcome

We used this realistic teleoperation scenario to perform a user study. We recruited 11 healthy subjects, aged 22-34, that had no prior experience in teleoperation. During the teleoperation the subjects could visually observe the slave robot and the collimator. This is expected to give the subjects better situational awareness, compared to observing the collimator through a 2D vision system, as traditionally used in teleoperation. Yet, part of the scene is still occluded by the hand and arm of the slave. Each subject was shown how to perform the task using teleoperation and was allotted to train the
removal and replacement of the cap using all control conditions. The training phase was conducted on location.

During each trial we record position and orientation of master, slave and collimator, the state of the hand (grasped/released) and the trial duration. In addition, we asked each subject to fill out a questionnaire about their experience with the proposed shared controllers.

![Figure 4: Summary of the phase durations for the three teleoperation conditions, evaluated at two locations of the collimator.](image)

All users prefer the learned shared control strategy over direct and unassisted manual control. They reported that although the subjects indicated that they prefer a form of shared control while performing teleoperation, our subjective evaluation does not show that either HSC or SSC increases the teleoperation performance; task execution time did not improve significantly. This contradicts previous work on shared control and a discussion on potential sources that could have caused this outcome are further discussed in the paper.