Data Collection Set-up

Our teleopeartion set-up is shown in the following figure. A UR3 cobot is fixed at the centre of a square table (side=1m). During the data collection for the evaluation purposes, the human operator performed movements in the quarter of the workspace closer to him. An ASUS Xtion pro was used to collect raw visual and depth information (sampling frequency: 30fps, resolution: 640x480). An augmented reality (AR) marker was used for identifying the pose of the camera with respect to the base of the UR3 cobot. All the evaluation data regrading robot performance are collected running the real robot.

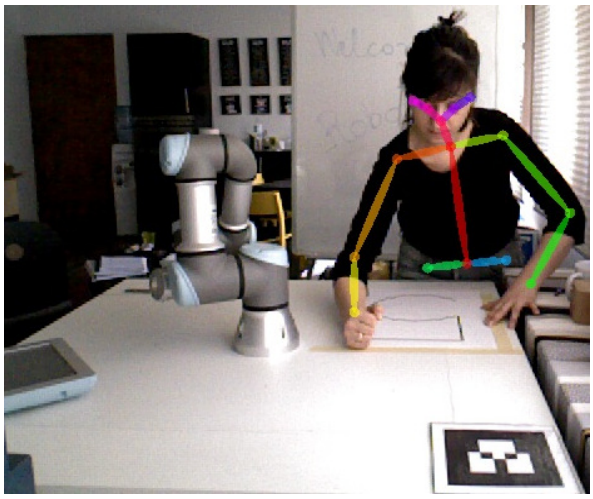

Figure 1: Data collection set-up. The human followed with her wrist printed paths attached to the workspace. The cobot did not occlude any part of the human's upper torso. The figure shows a frame from the RGB-D camera.

Dataset

For the evaluation of the control frameworks, we used 20 pre-recorded human movements of different shapes. One participant[1] followed with her wrist different paths on the surface of the workspace table. All paths were confined to a rectangular space (~30 x 42 cm); their details are presented in Table 1. The data collection was completed in two different days to account for different light conditions and differences in the performance of the participant due to fatigue, habituation, etc. Some movement shapes were repeated in both days. After inspecting the data, we did not observe any differences in the performance of the visual methods due to the different light conditions in these two days and so the data are not treated separately.

[1]One of the authors acted as participant. The dataset can be available upon request.

Table 1: Human movement dataset details

Shapes of paths (Ground Truth Length [m])	No trajectory points	
	F-movements	F/A-movements
Letter-Zed* (0.716)	52/31	73/56
Circle* (0.87)	48/30	81/79
Heart (0.88)	58	105
Letter-S* (0.51)	35	67
No-2 (0.77)*	64/55	74/80
No-3 (0.74)	41	102
No- 5 (0.91)	39	67
* These movements were performed on both data collection days		

The participant was asked to perform the movements under two different conditions "as fast and as accurate as possible" (F/A-movement) and "as fast as possible" (F-movement). We expected that these instructions would result in movements with significant differences in the execution speed based on the speed-accuracy trade-off and would allow us to evaluate the robot motion controllers for different human *movement speed* conditions. This was confirmed after analysing the movement speeds, measured as the ratio of the total travelled distance in each movement over the movement duration. The average movement speed was $0.42m/s$ ($SD = 0.106$) and $0.25m/s$ ($SD = 0.046$) for the F- and F/A-movements respectively. Both groups were normally distributed ($p > 0.05$ for both groups using a Shapiro-Wilk test) and they had equal variances (Levene's test, $p = 0.088$). A Student's t-test showed that the difference between the speeds in the two movement groups was statistically significant ($t(18) = 4.5, p < 0.001, d = 2.01$).

For the evaluation purposes, each movement was recorded in a separate rosbag. These rosbags were used as input to the ROS pipeline of this repo. Moreover, although the positions recorded included the 3D information, only the x-y plane information is considered in the analysis conducted in this work as the movements were performed on the surface of the table.