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Identifying human movement strategies for human-robot collaboration

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1. Introduction

Collaborative robotics is a promising solution to help address the issue of work-related musculoskeletal disorders, by providing physical assistance to workers. Collaborative robots can guide the human towards a more ergonomic posture, through repositioning of the robot end-effector (Busch et al. 2018). However, the pose of the robot end-effector only partly constrains the human whole-body posture. Owing to the kinematic redundancy of the human body, an infinity of postures can in theory be adopted for a same hand pose. In practice, human movements are largely stereotyped, which drastically reduces the number of observed solutions (Todorov 2004). Yet, some diversity remains: human kinematic redundancy is not always solved in the same way, referred to as “movement strategy” here (Bartlett et al. 2007). Thus, for a given task, different movement strategies exist, and the choice of a specific strategy depends on many factors both inter-individual (e.g. anthropometry) and intra-individual (e.g. fatigue). In order for a collaborative robot to provide an effective assistance, it is necessary to adapt the robot movement to the movement strategy of a specific user in a specific state (Yaacoub et al. 2023).

The work presented here aims at developing a methodology to identify movement strategies, and exploring their relation with factors such as fatigue or anthropometry. We collected a database of humans performing a repetitive manual task, in order to analyze the changes of movement strategies between individuals and across task repetitions. We plan to perform clustering on the collected data to systematically identify movement strategies. But due to the large number of degrees of freedom of the human body, movement strategies are observed in a high-dimensional space, which is ill-adapted for clustering techniques. Hence in a first step, we aim at defining indicators that accurately represent the diversity of observed movement strategies in a low-

dimensional space. This paper presents preliminary results investigating the relevance of the center of pressure (CoP) motion as a representative indicator.

2. Methods

2.1 Participants and protocol

5 participants (3 males, 2 females; height: 170 ± 5 cm; body mass: 66 ± 5 kg; all right-handed) participated in the experiment. The study was approved by INRIA’s ethical committee (n°2024-09).

The experimental task consisted of 2 consecutive trajectory-tracking sub-tasks –tracing a predefined path and erasing it– on a 1.18×0.78 m board, using a same portable tool (0.78kg). The path took about 40s to trace or erase. Participants were allowed to follow the path in either direction. They could use either hand to manipulate the tool, and change between trials. They were allowed to move their feet between trials, but not within a trial.

The task was performed in 7 different conditions, defined by the board’s height (3 heights, with board center at the participant’s hand height when arm extended at respectively 30° below (*low*), 0° (*medium*) and 30° above (*high*) horizontal) and inclination (3 for *medium* height: -60° , 0° , $+60^\circ$; 2 for *low* and *high* heights: -30° , $+30^\circ$ from plane normal to the arm axis). The order of the conditions was randomized to counterbalance fatigue or learning effects. Participants performed 6 consecutive trials in each condition, with a 20s break between trials, and a 5min break between conditions.

2.2 Instrumentations

Participants’ kinematics was recorded using the Qualisys motion capture system with 41 markers placed according to the QTM sports marker set (100Hz). Four AMTI force plates were used to record ground reaction forces (GRF) (100Hz). To monitor heart rate, participants were equipped with a Deslys Trigno EKG sensor (2000Hz). After the first and last trial of each condition, participants answered a Borg CR-10 questionnaire (Borg 1990) to estimate perceived exertion in each of the following body part: right/left arm and forearm, neck, back and legs.

2.3 Data analysis

The CoP position is reconstructed from the GRF measured by the force plates, after filtering the force data (4th order low-pass Butterworth filter, 5Hz cut-off frequency). Then the 95% confidence ellipsoid of the CoP positions is computed for each trial. The feet poses are obtained from the QTM software skeleton. Several metrics can represent the CoP confidence ellipsoid in a compact way, e.g. center position, main axes length, and orientation. Here, we focus on the ellipsoid orientation, wrt the axis parallel to the board.

3. Results and discussion

Visual inspection confirmed that various movement strategies were adopted during the experiment, both at intra- and inter-individual level. Some participants switched hand or trajectory direction across task repetitions. Participants adopted different feet positions, and sometimes put a knee on the floor. Fig. 1 shows the distribution of the CoP ellipsoid orientation in the *medium* +60° condition, for each participant. The CoP ellipsoid exhibits variations across trials and participants, with some participants displaying a narrow, and others a multi-modal, distribution. Interestingly, the distribution is larger in the *tracing* than in the *erasing* task, which may be due to a difference in task difficulty. Fig. 1 right shows that 2 instances of the CoP ellipsoid orientation correspond to different feet positions, which inevitably lead to different whole-body postures. Thus the CoP ellipsoid orientation has potential to serve for distinguishing movement strategies, though further analysis is needed and is on-going.

4. Conclusions

This work is a preliminary analysis of the database of human movements that we collected to analyze movement strategy choices. We showed that the CoP motion may be a promising indicator to characterize movement strategies. We plan to analyze more systematically the relation between the CoP indicator and observed movement strategies, and test if the application of clustering techniques on the CoP indicator results in meaningful classes of movement strategies. We will then analyze if the resulting classes

correlate with the fatigue perceived by participants, and/or with some anthropometrical features of the participants.

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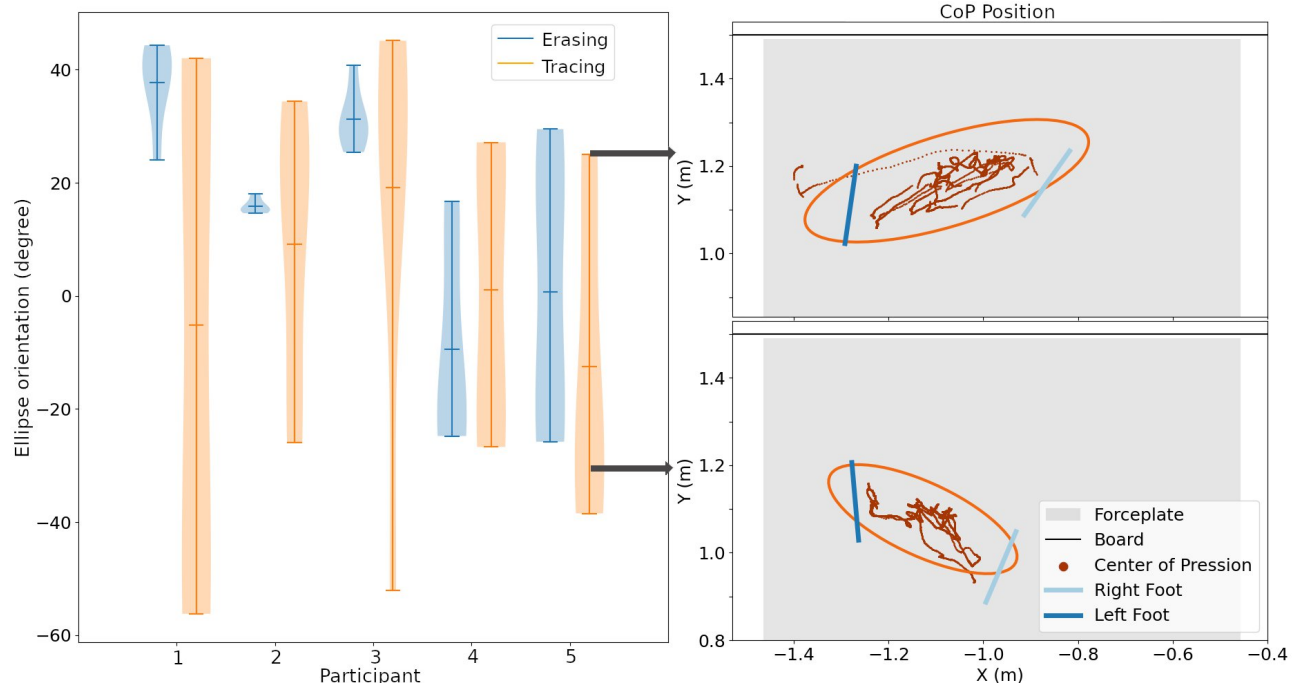


Figure 1 - Left: Distribution of the CoP confidence ellipsoid orientation in the *medium* +60° condition, for each participant for tracing and erasing . Right: Examples of CoP trajectory and confidence ellipsoid in two trials (tracing) of one participant, corresponding to different movement strategies.