Arm joint angle variability analysis in virtual robotic teleoperation with two master devices

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Introduction

- **Teleoperated robotic** systems are widely **spreading** in multiple fields: from **telemedicine** to **radioactive** materials **handling**.
- Users interact with a robot that acts as **master device**, controlling a slave manipulator that reproduce his/hers hand movements.
- While allowing for **increased precision**, **tremor compensation**, high **dexterity** and user **comfort**, teleoperation represents a **complex motor control tasks** that requires intensive training to master.
- This complexity comes from the **kinematic redundancy** that characterize the human arm: multiple joint configurations can be used to achieve the same hand movement.
- Previous works[1] analyzed how novice and expert users were differently **exploiting this redundancy** to **increase** their **performances** in teleoperation using the **Uncontrolled Manifold Analysis (UCM)** .

Goal

- In this work we propose the **use** of the **UCM** analysis as a way of **assessing** the **differences** between **two** different **master devices** in the motor control strategies adopted during the execution of **different tasks**.
- The UCM analysis allows for understanding **how different master controller designs** modify the way users coordinate the variability of their joint angles such that the **ratio between variability** that affects and that does not affect task performance **is reduced**.

Methods

Experimental Setup and UCM analysis

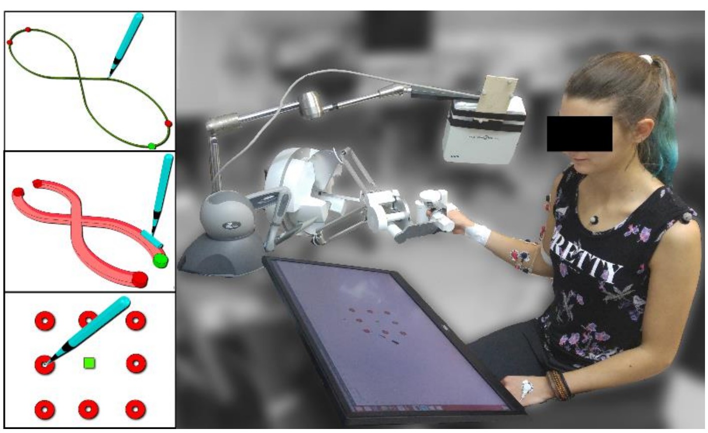


Fig. 1 - On the left, the three tasks developed; on the right, the user performs virtual teleoperation using the PL master device (Sigma.7). The arm and thorax movements are acquired with optical and electromagnetic markers

- The users performed **10 repetitions** of **3** different **tasks** using a **serial (SL)** and a **parallel link (PL) master device**
  - Following an half-cloverleaf trajectory
  - Following an half-cloverleaf trajectory orienting the tool tip
  - Reaching movements from a central position to eight targets
- **Arm** and **thorax motions** of eight right-handed users were acquired using **electromagnetic** and **optical** tracking **devices**.
- The joint angle vector ($\boldsymbol{\vartheta}$) was computed through **inverse kinematics** using a **seven-degrees-of-freedom musculoskeletal** model in **OpenSim**[2].
- Each repetition was **normalized in time** and the **mean joint angle** vector $\bar{\theta}$ was considered as the **reference** trajectory.
- The **arm Jacobian** (**J**) was **computed** for each time sample.
- The **deviations from the reference trajectories** were projected on the Jacobian null space and on its orthogonal matrix.

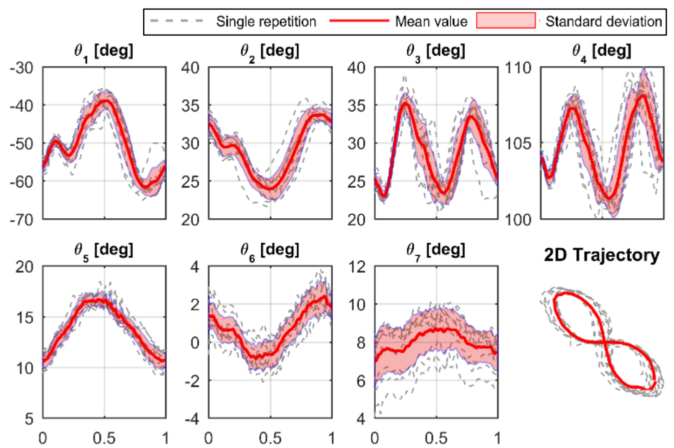
$$\theta_{TIM}(t) = \epsilon\epsilon^T\left(\theta(t) - \bar{\theta}(t)\right)$$
$$\theta_{TRM}(t) = \left(\theta(t) - \bar{\theta}(t)\right) - \theta_{TIM}(\mathrm{t})$$

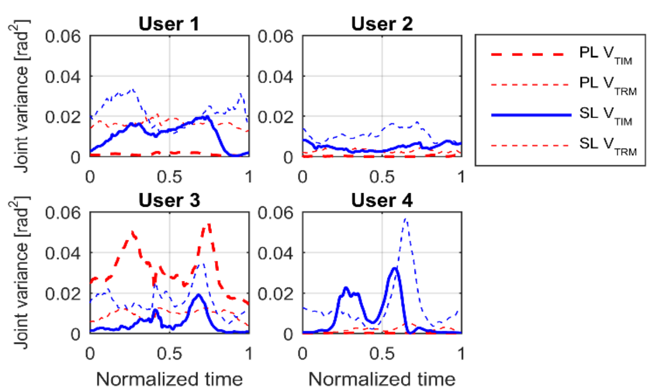
where $\boldsymbol{\theta}_{TIM}$(t) represents the **task-irrelevant manifold,** $\boldsymbol{\epsilon}$ is the null space of the Jacobian, and $\boldsymbol{\theta}_{TRM}$(t) represents the **task-relevant manifold**.

- The **variance per dimension** of the **norm** of **each projection** was computed.

Preliminary results

Joint angles variability





Discussion

- The **preliminary results** obtained studying only **4 users** and the **first task**, show that **the components** of **variance**, for **both** master devices, are **not constant through** the **trajectory**.
- Following **studies must** take into consideration the **different parts** of the **trajectory**, with different **curvatures** and **directions**.

Acknowledgements

This study is European Union's Horizon 2020 research programme (No. H2020-ICT-2016-732515), by the Israeli Science Foundation (grant #823/15), and by the Halmsley Charitable Trust through the ABC Robotics Initiative.

References

[1] Nisky, Ilana, Michael H. Hsieh, and Allison M. Okamura. "Uncontrolled manifold analysis of arm joint angle variability during robotic teleoperation and freehand movement of surgeons and novices." IEEE Transactions on Biomedical Engineering (2014)

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