Vibrotactile Feedback for Aiding Robot Kinesthetic Teaching of Manipulation Tasks

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Overview

- Kinesthetic Teaching
- Research Question
- Framework
- Experiment
- Results
- Conclusions

Kinesthetic Teaching

Robotic programming can be performed in several way. We are interested in the two ways that involve the physical demonstration by the Human Teacher

– Learning by Demonstration: the teacher shows what has to be done
– Kinesthetic Teaching: the teacher moves the robot

The former has issues of tracking system & kinesthetic mapping.

The latter involves a better knowledge of robot kinematics and dynamics

but feedback is necessary!

Feedback for Kinesthetic Teaching

- Examples of Challenges
  - Joint Limits
  - Singularity of robot kinematics
- Possibilities of Feedback
  - Visual Display: wearable, on-robot
  - Sound
  - Vibrotactile

Contribution

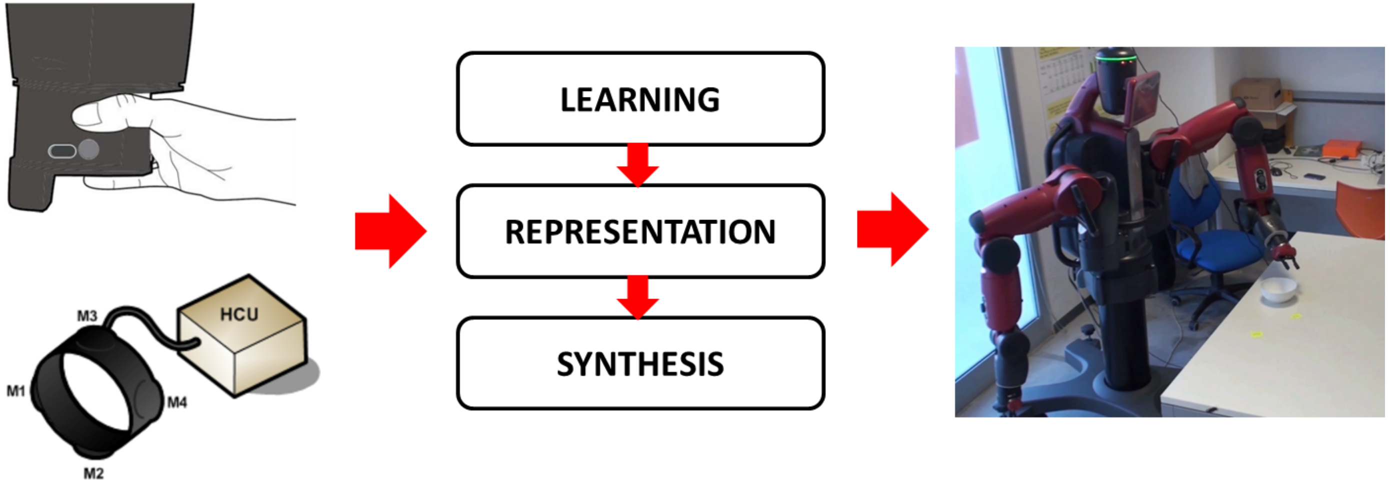
- **Focus**
  - Vibrotactile Feedback
- **Experimental Idea**
  - The human operator has to avoid paths where the robot loses degrees of freedom in order to provide good demonstrations (boundaries of the robot workspace, singular configurations).
  - Vibrotactile feedback to help refining demonstrations.
  - Motion representation: *Action Primitives* and spline functions.
- **Target Task**
  - Manipulation task consisting of a pick-and-place operation executed on a table

Framework

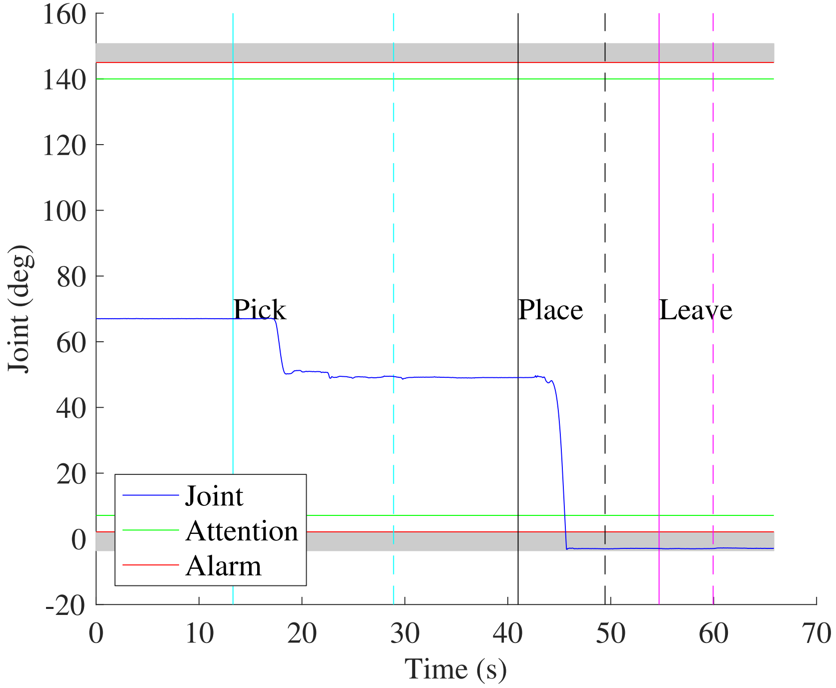
- Kinesthetic learning exploits the *Zero-G* mode of the Baxter robot
- Record the trajectory of the end-effector with the gripper states.
- Obtain a representation of the data recorded.
- **First** vibrotactile feedback: joint of the robot arm close to its limit.
- **Second** feedback: robot arm close to a singularity. Manipulability measure to characterize the distance from singularities

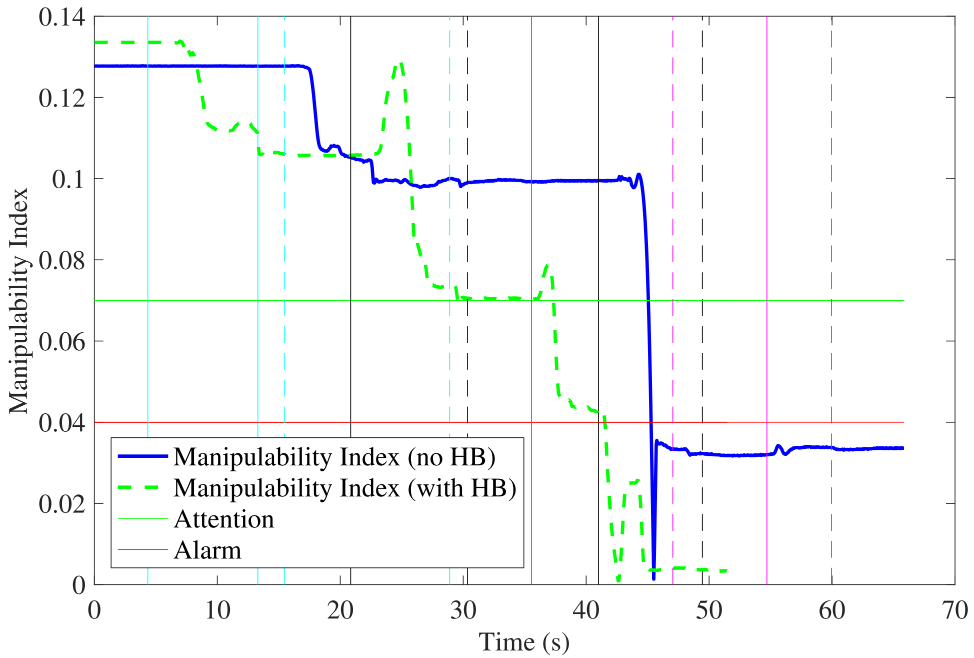
$$\omega = \sqrt{det\left(JJ^T\right)} = s_1 s_2 \ldots s_n$$

- Two level of feedback: attention and alarm.



Example of Feedback Profiles





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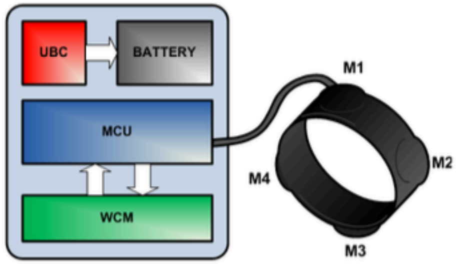
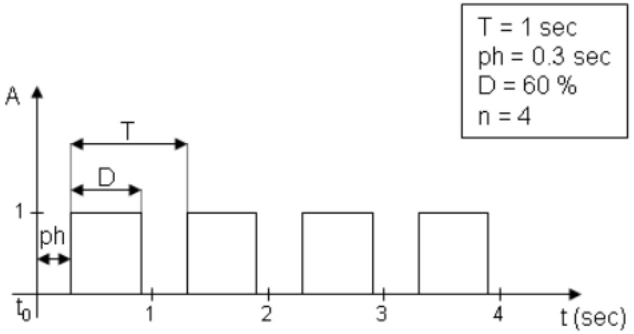
Vibrotactile Device

- 4 vibrating motors piloted via PWM
- Predefined set of square wave parameters for driving the motors.
- Parameters of the wave: pulsing period (T), phase (Φ), duty cycle (D), number of pulses (n).
- Bluetooth packet with 16 parameters.





Motion Representation

- *Action Primitives*: basic and atomic actions.
  - Pick-and-place task, three primitives: pick, place, leave.
  - Each primitive is a cubic spline function S (t):

$$S(t) = \{p_k(t),\ t \in [t_k, t_{k+1}],\ k = 0, \cdots, n-1\}$$
$$p_k(t) = a_0 + a_1(t - t_k) + a_2(t - t_k)^2 + a_3(t - t_k)^3$$

- n is not fixed: first derivative of trajectory steeper $\Rightarrow$ takes more points.
- Record x, y and z coordinates of the end-effector of the robot arm.

Task Playback

- For each *Action Primitive* we extract the points from the spline representation.
- Overtake the problem of positioning the object precisely in the same place of the learning.
- A software tool based on the direct triangular method in multiple view geometry, to recognize the object on the table by the two cameras on the Baxter's arms.
- Spline retargetting to adapt the splines to work with slightly different position of begin and end.
- The algorithm of spline retargetting. Four steps: compute the initial frame; compute the end frame; add the scale; compute the retargetted points.
- We use the Cartesian path planner of the software *MoveIt!* to execute the task

Experiment

- **Task**: Take an object from the table and put it in a bowl behind a small wall
- **Conditions**: vibrotactile feedback or not
- **Design**: Within-Subject
- **Subjects**: 10 participants ranged in age from 25 to 43 (average = 32) years old.
  - Almost all the participants knew the concept of joint limits and singularity, except one. Three of them have used kinesthetic teaching with robots before
- Each experiment consists of four parts: introduction, training, demonstration, interview.

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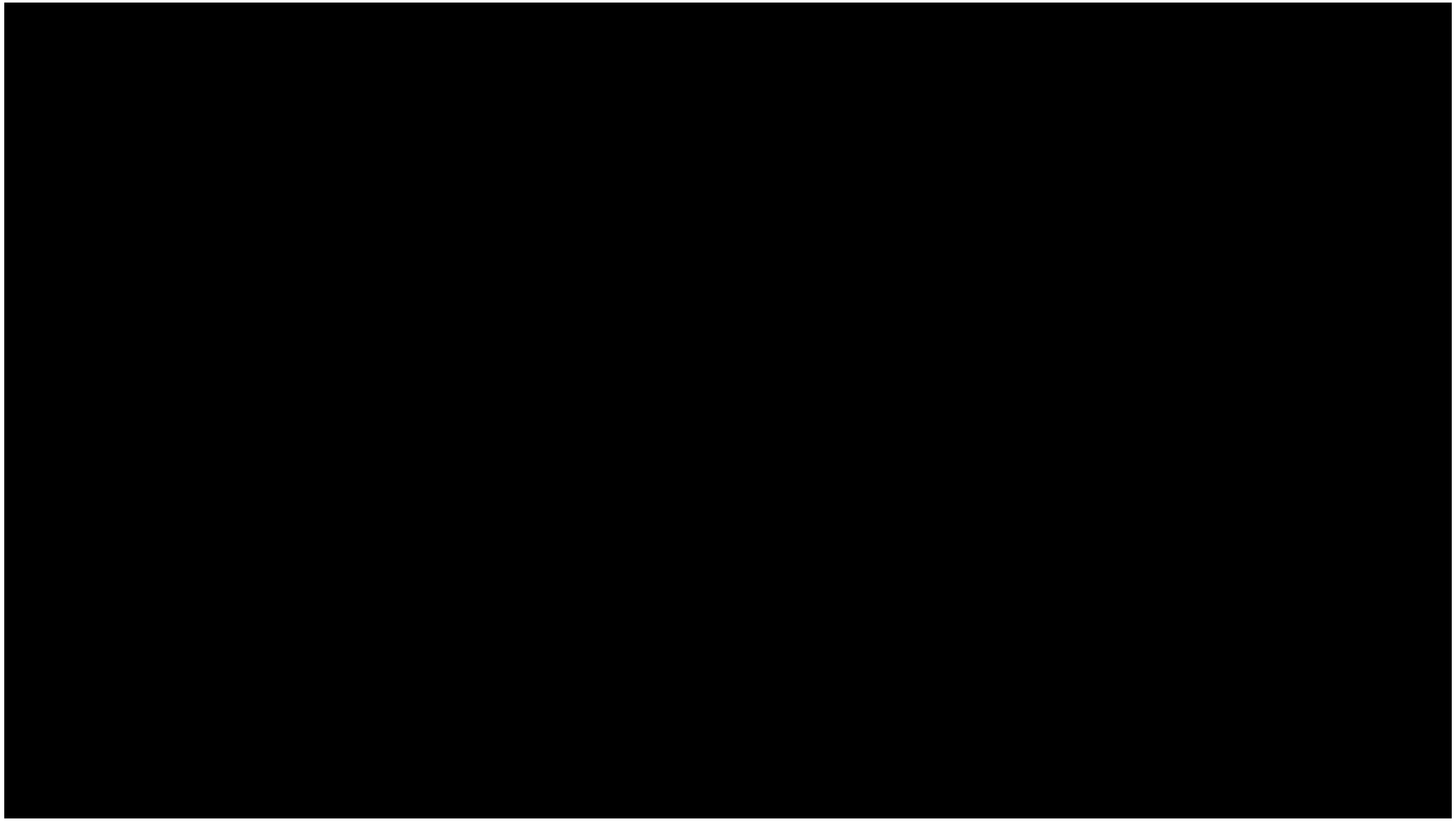
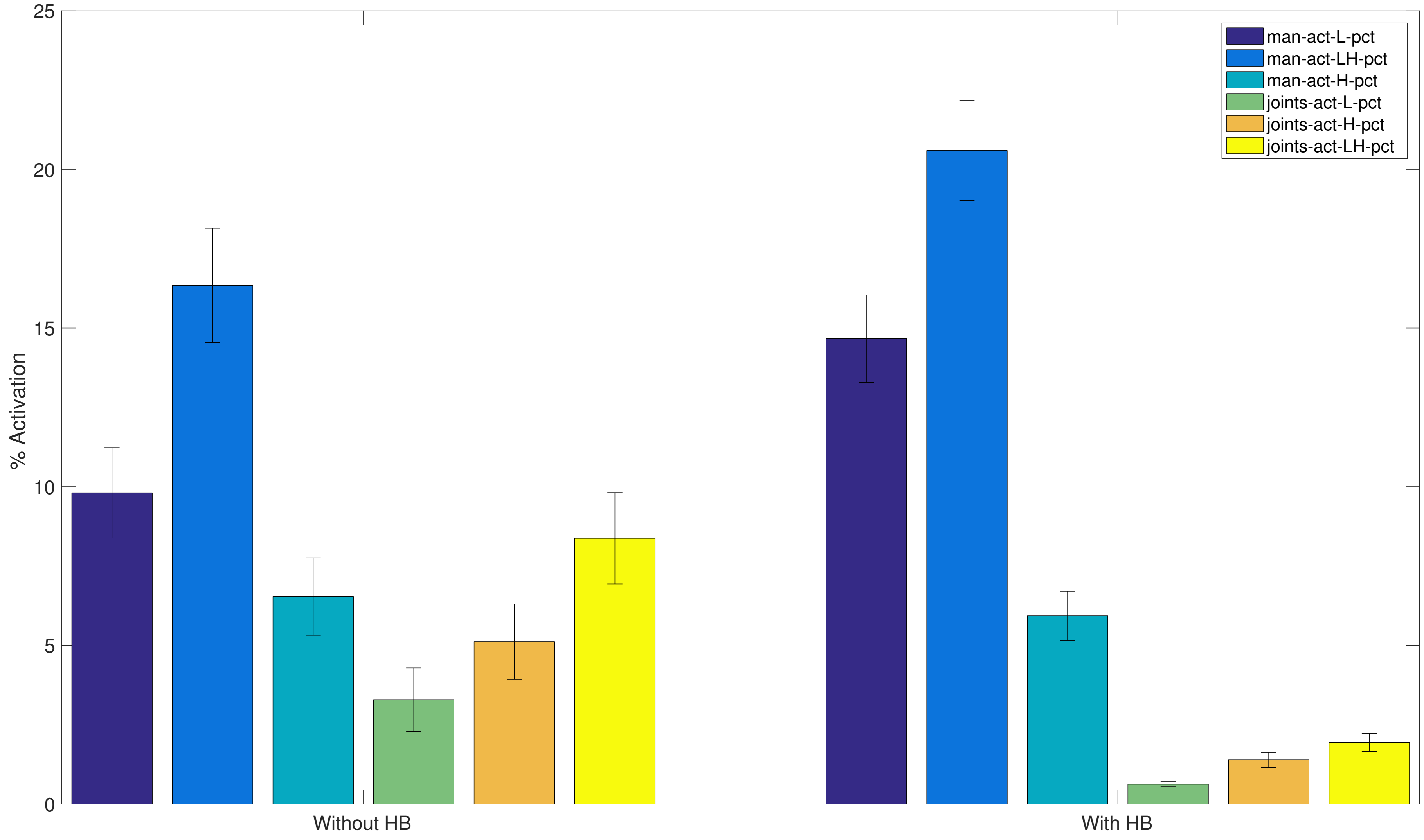
Video

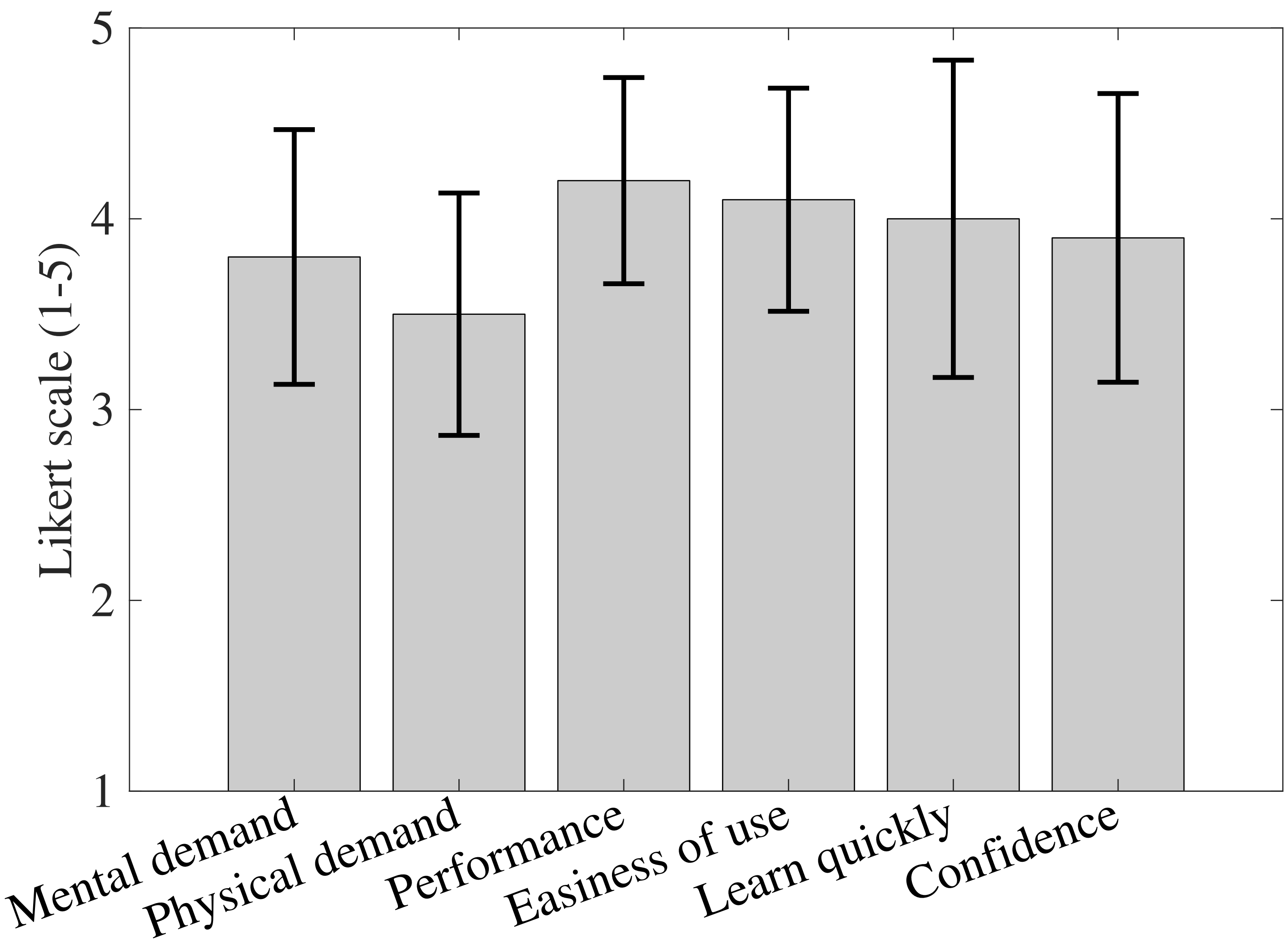


Quantitative Assessment



Aveage and Error Bar / no HB on the left, with HB on the right

Subjective Results



Average and 95% confidence interval

Results

- Duration Statistics: first session with HB made the second session quicker
- Man/Joint Limits Duration:
  - Manipulability was higher in HB tasks
  - Joint limits were lower in HB tasks
- Questionnaires:
  - task is considered physically (motor) demanding due to the type of Baxter's arms
  - feedback was effective in providing information to the users.

Conclusions

- Vibrotactile devices are promising for Kinesthetic Teaching feedback
- Specific effort is necessary for mapping measures & errors with feedback
- In particular it is advisable to correlate orientation of the bracelet with the motion of the user

Thanks

- Contact: e.ruffaldi@sssup.it
- Github: https://github.com/eruffaldi/paper_vibroteach

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http://www.taum.eu/

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