Toward Active pHRI: Quantifying the Human State During Interactions

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I. Introduction and objectives

The introduction of robots in human populated environment leads to inevitable direct (or indirect) physical interactions, especially under unexpected circumstances due to human error and/or uncooperative behaviors. In our recent publications [1], [2], we defined ”active physical human-robot interaction” (*active pHRI*) as a type of interaction during which the robot may take a physical action on the user without prior notifications, which can occur in several situations such as the ones depicted in Fig. 1. While physical safety is a top-priority in such scenarios, psychological and mental states should also be considered to ensure comfortable user experiences in both working and domestic environments.

In the state-of-the-art, despite recent increasing interest towards perceptions in the context of pHRI, there is currently no work addressing unanticipated and not necessarily predictable physical actions from the robot. Our objective is to build a quantifiable human state that is comprehensive of both the physical and mental states, which could be used in the control framework of the robot for real-time adaptations during active pHRI. This abstract summarizes our recent publication in IEEE Transaction on Human-Machine Systems [2], which details an exploratory study that aims at understanding the human perception and behaviors, and builds toward a human-state model that is based on quantifiable data. The experiment we conducted aims at verifying the following hypotheses:

- **H1** Unanticipated robot actions cause measurable alterations in the users' physical and physiological data;
- **H2** Physical and physiological data measured during the interaction could be explained with users' personalities and perceptions of the robot.

Where the term *unanticipated* refers to an action that the user might not be expecting or not knowing when it is being executed.

II. Method

We designed an experiment in which the user has to use a collaborative robot arm (7 DoF) to play a visual game. The

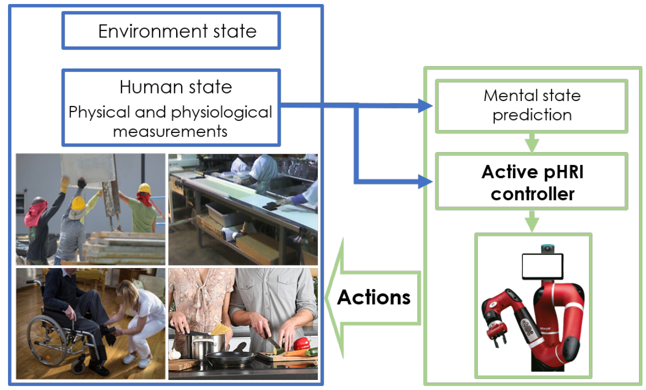

Fig. 1. In situations where active pHRI may occur, the robot should take actions based on the humans' physical and mental states, which could be predicted/inferred from measurable physical and physiological data.

game consists of a coin-catching game in which coins of different values can be caught by moving a catcher horizontally on the screen. To move the catcher, the user needs to physically move the end-effector of the robot, establishing a direct physical contact. The experiment consists of five sessions, two *Trial sessions*, during which the robot does not take any physical action, and three *Active sessions*, during which the robot has the objective (hidden to the user) of catching high value coins, which is implemented using a quadratic programming formulation with a position task which target is the location of a high value coin. The participants are not informed beforehand that the robot will take such physical actions.

Both physical and physiological data are collected from the user: whole-body motion capture, ground reaction forces, interaction forces at the end-effector, eye-tracking with blinking and gazing times, Galvanic Skin Resistance (GSR) and Pulse Rate Variation (PRV). The participants are also asked to complete the Big-Five personality questionnaire [3] before the experiment, the CH-33 [4] questionnaire on perceptions of robots after the Trial sessions and after the Active sessions, the Self-Assessment Manikin [5] on emotional state after the Trial session and each Active session, and the Negative Attitude Towards Robots Scale (NARS) [6] at the end of the experiment. Finally, a semi-structured interview was carried out by a social scientist at the end of the experiment to qualitatively assesses the participants' understanding of the robot's actions.

We performed the experiments with a total of 40 participants of Japanese background (born and raised in Japan), of which 35 were retained for the data analysis. All our experiments have been approved by the local ethics commit-

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tee at the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan. Before the experiment, participants received proper information and have given an informed consent to participate in the study.

III. Data analysis

The data has been processed into a series of *factors* on which the analysis is carried out. These factors include: distances between participants' body segments and the robot, average eye-blinking rate and durations, average interaction forces, questionnaire outcomes, percentage differences between Active sessions and Trial sessions, etc. For a full list, please refer to [2].

The semi-structured interview was used to categorize participants. Two categories were extracted from the answers: the robot intention's understanding and the perception of the robot's helpfulness. Of the 35 participants, 22 participants understood the intention of the robot, and 13 did not. 18 participants found the robot helpful while 17 did not or not completely. An in-depth analysis of the interviews from social sciences perspectives was not conducted at this time as it is out of the scope of the paper.

The analysis aimed at addressing the two hypothesis: for **H1**, we performed correlations between the percentage differences and variance tests, for **H2**, we performed correlations between the factors. In particular, we looked at differences between the categories obtained from the semi-structured interview. We then performed clustering analysis as a first step toward building the human state model.

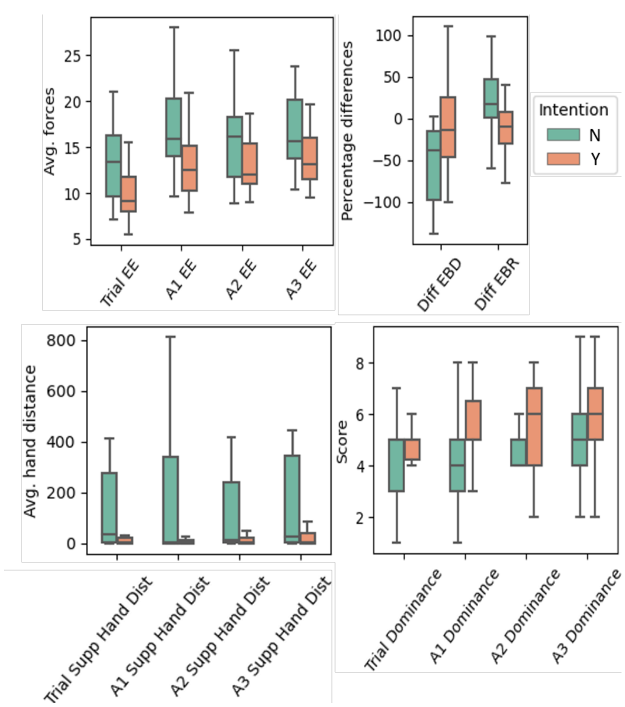

Fig. 2. Factors with relevant differences when comparing participants who understood the intention of the robot (catching high-value coins) and those who did not.

IV. Results and discussions

While detailed outcomes can be found in [2], we briefly summarize here the major findings and contributions of this exploratory study. To the best of our knowledge, this was the only experiment (except for our work in [1]) targeting active pHRI and systematic analysis of factors relevant to the comprehensive human state.

The results showed that participants clearly felt the physical actions of the robot, and these physical actions caused alterations in both their real-time measurable state, as well as their perceptions from the questionnaire outcomes. It is interesting to note that the perceptions did not change in the same way for all participants, indicating that personal factors such as age and personality can play an important role. For example, extroverted participants preferred to stay closer to the robot during the active session. Interesting results also emerged by comparing the categories obtained from the semi-structured interview, for example in Fig. 2, we can observe that participants who understood the intention of the robot (catching high value coins) used lower forces, had lower mental load, kept their hands closer to the robot, and felt more dominant with respect to those who did not understand. The results confirmed that the robot action does cause alterations in the participants' physical data and perceptions, but not in a significant way the physiological data, and that there exist relevant relationships between physical and physiological data and personalities and perceptions, and also between perception and personalities.

The findings could be used to build a human state model for use in the control of robots during active pHRI. To do so, an important next step is to reduce the number of factors for two purposes: reduce the sensor load on the user, and simplify the model. Especially, interaction forces at the end-effector appeared to be a relevant factor, which can be easily measured on most state-of-the-art collaborative robots, and user postures could be inferred from non-invasive setups such as video cameras. As potential future developments, long-term interactions with active pHRI should be addressed.

References

[1] Y. Hu, M. Benallegue, G. Venture, and E. Yoshida, "Interact with me: An exploratory study on interaction factors for active physical human-robot interaction," *IEEE Robotics and Automation Letters*, vol. 5, no. 4, pp. 6764–6771, 2020 (preprint: https://hal.inria.fr/hal-02957318v1)

[2] Y. Hu, N. Abe, M. Benallegue, N. Yamanobe, G. Venture, E. Yoshida, "Toward Active Physical Human-Robot Interaction: Quantifying the Human State During Interactions",*IEEE Transaction on Human-Machine Systems*, Early Access, February 2022 (preprint: https://hal.inria.fr/hal-03567276v1).

[3] G. M. Hurtz and J. J. Donovan, "Personality and job performance: The Big Five revisited." *J. of Applied Psychology*, vol. 85, no. 6, p. 869, 2000.

[4] H. Kamide et al "Development of a scale of perception to humanoid robots: PERNOD". In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 5830-5835, October 2010.

[5] M. M. Bradley and P. J. Lang, "Measuring emotion: the self-assessment manikin and the semantic differential," *J. of behavior therapy and experimental psychiatry*, vol. 25, no. 1, pp. 49–59, 1994.

[6] T. Nomura, T. Kanda, T. Suzuki, and K. Kato, "Prediction of human behavior in human–robot interaction using psychological scales for anxiety and negative attitudes toward robots," *IEEE Trans. on Robotics*, vol. 24, no. 2, pp. 442–451, 2008.