Interact with me: active physical human robot interaction

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I. Introduction and objectives

In current state of the art physical human robot interaction (pHRI), many researches deal with one major topic: safety [1]. With the introduction of cobots, the safety standards ISO/TS 15066 [2] have been updated with strict rules and limitations to be imposed on robots that are meant to come in direct physical interaction with humans.

In trying to achieve safer physical interactions, often the robot is overly constrained in both speed and force, becoming rather ”passive” when in *direct contact* with humans, where with *direct contact* we refer to the human physically touching the robot with their hands or other body parts.

However, we believe that to maximize the efficiency of the use of robots, robots of the future should be able to actively help people in their duties and act in an ”active” way, therefore we refer to this as ”*active physical human robot interaction*”. To this end, robots should be able to adapt to the human counterparts during the interaction, i.e. be ”active” and at the same time be ”human aware”. Our final goal is to implement a new optimal control architecture that takes into account *interaction factors* extracted from analysis of physical human robot interactions, within the current safety standards or proving the necessity of breaching current safety limitations. In this abstract we present the first step towards our final goal, which is the design and implementation of the experiment to identify interaction factors.

II. Design of the experiment

Three parties are involved in the experiment:

- the robot, which in our case is a Sawyer (Rethink Robotics) manipulator (Fig. 1)
- the user, who is the subject of the experiment and is involved in an *active physical human robot interaction* with the robot (Fig. 1)
- the guide, who controls the experiment and can stop the robot at any time.

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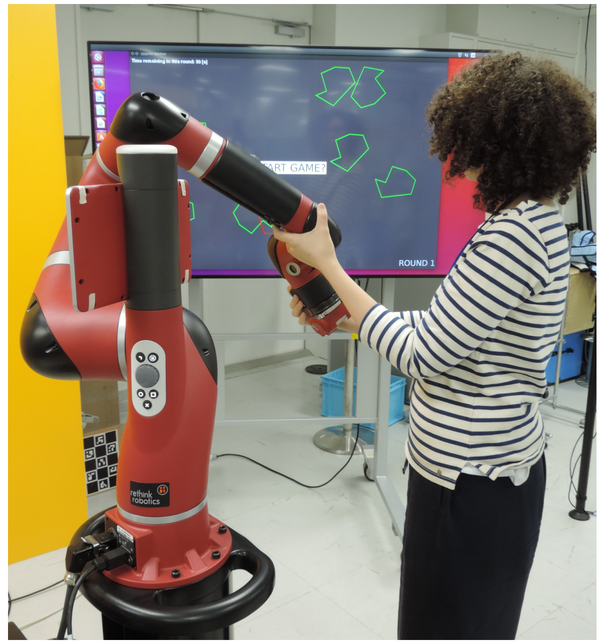

Fig. 1. Overview of the human and robot during the *active physical human robot interaction* used in our experiments.

During the experiment, the user is asked to use the robot as a joystick to play a puzzle matching game as in Fig. 1. By moving the end-effector of the robot, the piece in the game screen is moving (Fig. 1). The robot can be moved in 3D space (with 6D motions), and the motion is projected into 2D space (with 3D motions: position and orientation of the piece in the game).

At specific timings, the robot performs an active motion (e.g. a push or pull) on the user. Otherwise it is passive, with a gravity compensation scheme only. The users are not warned beforehand about the action of the robot because the goal of the experiment is to evaluate not only the state of humans when interacting physically with a robot, but also the reaction of humans towards active actions of robots, in both expected and unexpected situations.

The user is equipped with optical (or inertial) motion capture system, heart rate monitor, and galvanic skin sensor, to collect measurements that can be used to analyse the physical and physiological state of the human throughout the experiment. In addition, an eye tracking system is used to track the sight directions of the user. For example is the human looking at the robot or at the game screen? From the robot side, data from available sensors are collected, including the joint positions, velocities, torques, as well as wrenches at the end-effector. At the end of the experiment, the users are asked to answer two state of the art questionnaires, i.e. the PERNOD [3] and the Godspeed [4], such that experiment data can be interpreted in a meaningful manner.

From the available measurements, we consider the following factors as candidate interaction factors:

- heart rate variations;
- emotional stress from galvanic skin sensor;
- frequency, timing, and duration of gazing the robot;
- forces exchanged between the user and the robot;
- distance of the user from the robot (both base and end-effector)
- velocity and accelerations of the motions of the user (e.g. displacement of the lower body, displacement of the upper body, and relative displacements).

The actual role and contribution of these factors are to be evaluated with experiments, where we also expect new factors to emerge with the acquired data and observations from the experiments.

III. Implementation of the Experiment

The robot we use is a Sawyer manipulator by Rethink Robotics, which has 7 DOF (Degrees of Freedom). It is torque controlled and equipped with Series Elastic Actuators (SEA), and it complies with the safety standards ISO/TS 15066.

We overwrite the high-level control architecture of the robot, by implementing damped gravity compensation, where the damping torques are computed as:

$$\boldsymbol{\tau}_d = \boldsymbol{\lambda}\mathbf{M}\dot{\mathbf{q}} \tag{1}$$

where λ is a vector of constant factors to regulate the contribution of the damping over different joints, $\mathbf{H}$ is the inertial matrix of the manipulator and $\dot{\mathbf{q}}$ is the joint velocities vector of the manipulator. The active force injected to perform robot active motion is computed as follows:

$$\boldsymbol{\tau}_a = \mathbf{J}_e^T \mathbf{f}_a \tag{2}$$

where $\mathbf{J}_e$ is the Jacobian at the end-effector and $\mathbf{f}_a$ is the desired active force. The active force is proportional to the force exerted by the user on the end-effector (Fig. 2), bounded in a specified minimum and maximum magnitude, to ensure that the force is perceived yet at the same time safe for the user. In future experiments we plan in extending the control architecture by introducing constraints such as Cartesian operational space, velocity at the end-effector, and postures, via a QP (Quadratic Programming) formulation [5], to ensure higher safety for the users as well as to be able to control the experiment in a better way.

The robot is interfaced via ROS (Robot Operating System) [6] and the control module is currently implemented in Python with the Intera SDK from Rethink Robotics, but will be extended to a C++ controller for the above cited QP formulation. The game is also implemented in Python using the Pygame package, and is interfaced with the robot via ROS as well.

We have performed preliminary tests to verify the suitability of the experiment, and have observed that the active force

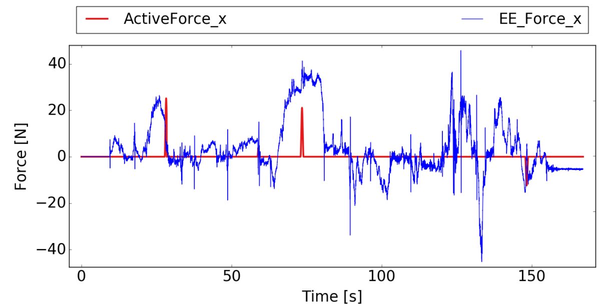

Fig. 2. Example of active force profile (in red) in x direction, with measured end-effector force (in blue), during an experiment.

of the robot on the human can induce to different reactions according to the magnitude of the force. When the robot performs a large motion in order to achieve the desired force, the user is generally more surprised with respect to when a force of similar magnitude is exerted but with a more contained motion. Also, we have observed that users with different body strength perceive the active force differently, so we might introduce an initial calibration phase to properly scale the active force according to the user. After the first few times in which the active force is exerted, the user acquires the knowledge about the active force and has an expectation towards it, therefore the active action looses the surprise factor. We can use this knowledge to evaluate the reactions of users on a habituation curve, or to re-adjust the active force to reinforce the surprising effect.

IV. Perspectives and Future Developments

Extensive experiments will be carried out with several subjects to collect data in a statistically significant way, in order to identify the aforementioned interaction factors, by combining the measurement data and the questionnaires outcomes. As these factors are identified, they will be introduced in our control scheme and further experiments will be carried out to validate the identified factors.

All our experiments are approved by the local ethics committee at the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan. Before the experiment, participants will receive proper information and give an informed consent to participate in the study.

References

[1] Bicchi, A., Peshkin, M. A., & Colgate, J. E. (2008). Safety for physical human-robot interaction. Springer handbook of robotics, pp. 1335-1348.

[2] Standard, I. S. O. "ISO/TS 15066: 2016 Robots and robotic devices-collaborative robots." (2016).

[3] Kamide, H., Mae, Y., Takubo, T., Ohara, K., & Arai, T. (2010, October). Development of a scale of perception to humanoid robots: PERNOD. In 2010 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 5830-5835.

[4] Bartneck, C., Kulić, D., Croft, E., & Zoghbi, S. (2009). Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. International journal of social robotics, 1(1), pp. 71-81.

[5] Vaillant, J. et al. (2016). Multi-contact vertical ladder climbing with an HRP-2 humanoid. Autonomous Robots, 40(3), 561-580.

[6] Quigley, M. et al. (2009, May). ROS: an open-source Robot Operating System. In ICRA workshop on open source software, Vol. 3, No. 3.2, p. 5.