

Interact with me: first insights into active pHRI

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I. INTRODUCTION

Human-robot interaction (HRI) is a topic of major interest in the robotics community, where robots are envisioned to be used for interacting with humans not only socially, but also physically. Therefore, safety has been one of the main concerns [1], mainly when physical contact may happen or is necessary. Safety standards for collaborative robots have been introduced in ISO/TS 15066 in 2016 [2], where a set of limitations and strict rules have been imposed.

In the state-of-the-art research on HRI, physical human-robot interaction (pHRI) is often more focused on the development of controllers, while social human-robot interaction (sHRI) is more focused on the evaluation of the perception, e.g. sense of comfort, safety of the user with respect to robots, often by means of post-experiment questionnaires. In sHRI there is generally no physical contact between the human and the robot, whereas in pHRI the social aspects are usually not taken into account, and robots are often over-constrained to ensure the aforementioned safety, becoming rather “passive” and “slow”.

We believe that the efficiency of physical interaction with robots could be boosted with “active” interactions. We refer to this as *active physical human-robot interaction* (active pHRI), i.e. an interaction during which robots may take autonomous physical actions on the human without prior notifications. 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”. In this work, we attempt at addressing the identification of possible useful *interaction factors* during active pHRI that could be used for the future development of active controllers, by combining methodologies from both sHRI and pHRI, analyzing the users’ state via both physiological data, physical data, and questionnaires. As physiological and physical data alone are of difficult interpretation, we try to find correlations that may give interesting insights.

In the rest of this manuscript, we describe the active pHRI

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Fig. 1: Active physical interaction experiment. The user uses the robot as joystick to play a puzzle game.

experiment that we designed and implemented to identify the interaction factors, as well as the first obtained results, which show that we can extract promising factors related to the perception of the robot, the personality, and the physiological and physical data of the users.

This extended abstract is a summarized version of the paper [3].

II. EXPERIMENT DESCRIPTION

The experiment is described in a general way in Fig. 2, it consists in the user using the robot as a joystick to play a puzzle game, shown on a screen (as in Fig. 1). The goal of the game is to match the blue piece into the red one as shown in Fig. 2. During the interaction, the robot performs actions on the user by pushing or pulling with an active force. Details about the control of the robot and the interaction of the game are explained in the next sub-sections.

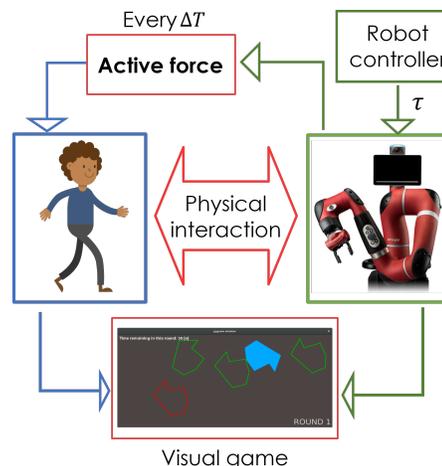


Fig. 2: Schematic description of the experiment.

A. Equipment and sensors

The robot we use for the experiment is a Sawyer collaborative robot (Rethink Robotics), which has 7 degrees of freedom (DOF). It is torque controlled and equipped with Series Elastic Actuators (SEA), and it complies with the safety standards ISO/TS 15066. The robot has joint torque sensors in every joint, which are also used to estimate the external wrench at the end-effector.

In order to measure the state of the user during the experiment, we use the following equipment and sensors:

- Galvanic Skin Resistance (GSR) and photoplethysmography (PPG) sensor, Shimmer3 GSR+ Unit (Shimmer Sensing), a wireless sensor with bluetooth that records GSR and PPG data locally on a SD card. The GSR is recorded via two single-use gel type electrodes, while the PPG via an earlobe clip optical sensor;
- Eye tracker, Pupil Core (Pupil Labs), an open source eye tracking platform connected via USB-C. We use a single eye tracker on the right eye;
- Camera based motion capture system of Motion Analysis, with 11 cameras;
- 4 Bertec force plates, synchronised with the motion capture system.

The GSR electrodes have been positioned at the back of the neck. The PPG measurement is used as an alternative to the measurement of Heart Rate Variation (HRV), from the PPG signal we extract the Pulse Rate Variability (PRV). The eye tracker measures the gaze position, the dimension of the pupil, the blinking durations and timings, and records videos of both the eye and the world via two cameras positioned on the glasses.

For the motion capture we use a set of 23 markers: 3 on the head, 1 on each hand and 2 on each elbow, 2 on the front of the torso, 4 on the back and one on each shoulder, and 3 on each foot. The markers are pre-positioned on wearables that can be worn on top of the users' clothes. We also position three markers on the robot, on the tip of the base, the elbow, and the wrist, respectively. For the positioning of the sensors and markers, please refer to Fig. 1.

B. Robot control

In order to play the game using the robot, the user has to press the interaction cuff button located on the end-effector of the robot. The user is free to move the robot in any direction, the 3D Cartesian space motion is projected into the 2D movement of the blue piece. The rotation of the piece is a direct mapping of the joint angle of the wrist joint. If the button is released, the robot motion stops.

The robot is torque-controlled when the user presses the cuffs, otherwise it is position-controlled. We override the high-level control of the robot with a controller that runs at a frequency of 100 Hz, implemented using a Quadratic-Programming (QP) [4] formulation which allows to take into account joint limits, joint velocity limits, as well as joint torque limits. During the game, the robot takes a timed action on the user, i.e. every $\Delta T = 5$, an *action force* \mathbf{f}_a is applied for a duration of $\Delta T_a = 1$.

The direction of \mathbf{f}_a is opposite to the estimated end-effector velocity direction at the instant the active force starts to be applied. The magnitude is proportional to the force exerted by the user on the end-effector. The active force is applied only when the user is pressing the cuff, therefore when the robot is in torque control.

C. Experiment protocol

Every experiment follows strictly the same protocol. Before the experiment, the participants read the experiment protocol and watch a pre-recorded video explaining how to interact with the robot and how to play the game. The participants are not informed about the possibility of the robot to perform actions, as we are interested in the natural reaction to unexpected independent actions by the robot on the user.

Before the beginning of the experiment, the participant is asked to complete a simplified version of the Big Five personality traits questionnaire consisting of 20 questions [5]. Then they are equipped with sensors and markers and rest for about 10 minutes, during which the GSR and PPG baselines are recorded. The participants first perform two trials of the experiment without active force, then the experiment is carried out three times consecutively. The participants are asked to keep playing the game until instructed otherwise, as winning and/or losing is not the goal of the experiment. Each experiment is video recorded from both the front and the back. At the end, the participant completes two questionnaires: CH-33 [6], which has been established as a measurement of psychological safety towards robots [6], and the Godspeed Series Questionnaire (GSQ) [7].

III. RESULTS AND DISCUSSION

We performed the experiment with a total of 23 subjects, however, only the data of 17 subjects were usable due to technical issues. In the final set of 17 subjects, 7 are females and 10 are males, with age between 20 and 33 years old. To avoid possible cultural dependent variabilities, all the participants are Japanese, born and raised in Japan. All our experiments have been approved by the local ethics committee at the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan. Before the experiment, participants have received proper information and given an informed consent to participate in the study.

A. Data collection

Due to the amount of data and high number of variables that can be extracted from the collected data, here we consider and analyze only a subset consisting of:

- PPG, in particular the derived PRV, which is the peak-to-peak interval variability of the PPG signal;
- Eye blinking frequency and duration (EBR, EBD), pupil diameter;
- Center of pressure (CoP) computed from force plates;
- Interaction forces measured at the robot end-effector;
- Interaction frequency, in terms of frequency of the pressing of the cuff;

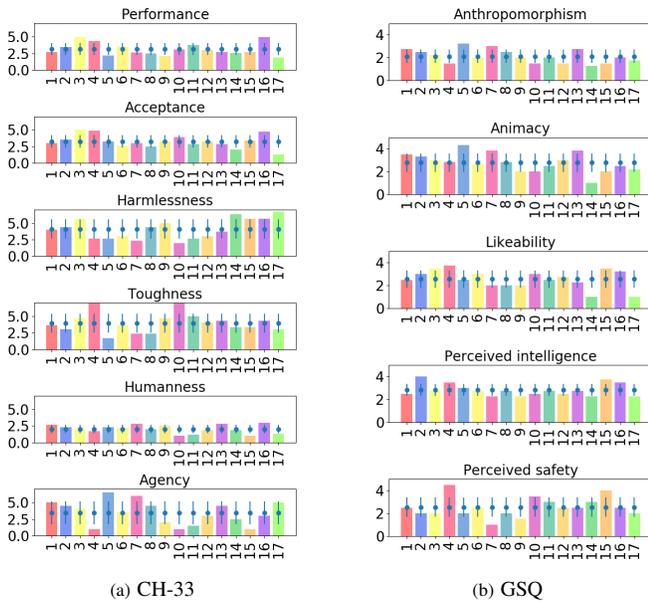


Fig. 3: Results of the questionnaires CH-33 (a) on a scale of 1-7, GSQ (b) on a scale of 1-5, for the 17 participants considered in this study, the error bar shows the mean and standard deviations of the factor for all the subjects. It is interesting to note that the participants had overall different perceptions of the robot, in some cases with completely opposite outcomes (e.g. subjects 4 and 5 in CH-33).

- Number of actions occurred, e.g. the number of action forces applied, the number of games won;
- Qualitative assessments from video recordings;
- Questionnaires results;

where we compute also difference percentages between stimuli (e.g. action force application, game winning, etc.) and the overall experiment. Here we will mainly consider the action force application, by using a window of 3 seconds from the start of the stimuli, to which we will refer as “action window”. The remaining data that are not used in this manuscript will be used in further extended analyses.

After post-processing, we extracted 82 factors mainly based on statistical analysis, including the questionnaires outcomes. In particular, the personality test projects into 5 factors: extraversion, neuroticism, openness, conscientiousness, agreeableness. The post-experiment questionnaire CH-33 consists of 33 questions rated on a 7 points Likert scale and projected onto 6 factors, as shown in Fig. 3a, while GSQ is a series of 5 questionnaires rated on a 5 points semantic differential scale, resulting in 5 factors as shown in Fig. 3b. From Fig. 3 we can observe that except for Humanness that is low across all participants, there is no specific trend of the questionnaire outcomes, indicating that the subjects had overall different perceptions of the robot. We consider therefore interesting to analyze the correlation between the factors to identify relationships between perceptions, personality, and measurements.

The qualitative assessments from the video recordings mainly concern the general behavior of the participant throughout the experiments, e.g. how far do they keep the robot end-effector from their body, where do they put their hands, do they face the robot or the screen, do they prefer

to walk around or not, do they have any reaction when the action force is applied?

B. Extracted factors

We performed Pearson’s correlation on all the factors, and extracted those with correlation coefficient $|r| > 0.6$ and p-value $p < 0.05$. We will not list all the extracted factors and summarize only the interesting ones, as shown in Table I. We give a brief explanation of the meaning of the factors:

- Harmlessness, one of the CH-33 factors, indicating the perception of the obedience of the robot;
- Extraversion, which is outgoing/energetic (100) vs solitary/reserved (0);
- Conscientiousness, which is efficient/organized (100) vs easy-going/careless (0);
- Cuff frq diff, is the difference percentage of the frequency of pressing the cuff during the action window, with respect to the average of the experiment, if positive, the frequency is higher during the action window;
- EBD diff, is the difference percentage of the average eye blinking duration during the action window, with respect to the average of the experiment, if positive, the duration is longer during the action window than on average;
- PRV diff, is the difference percentage of the PRV during the experiment with respect to the baseline, if positive, the rate is higher during the experiment than the baseline;
- CoP and CoP F, the distance measured in terms of CoP, between the subject and the base of the robot, CoP is the average over the experiment, while F indicates the distance at the instant the interaction has started, i.e. the cuff has been pressed;
- Torso distance, qualitative assessment of the position of the end-effector with respect to the torso of the participant, rated 1 for close distance and 2 for far distance;
- Walking, rated from 1 to 3 (not walking to walking a lot), qualitative assessment of the amount of walking during the experiment;
- Wins, the number of games won during the experiment;

Qualitative factors are not differentiated for each single experiment as it has been observed to be a general behaviour of subjects during all of their experiment sessions. Other factors are computed for each experiment separately, where “Trial” indicates the second trial¹, and Exp0j, $j = 1, 2, 3$ refers to the three experiments. For these factors, in the table we summarize those that have high correlation coefficient for at least two experiments.

From the results in Table I we can observe the following:

- Harmlessness has an inverse correlation with walking, this indicates that subjects who perceive the robot as more obedient, walk less during the experiment;

¹The first trial is, for the time being, not considered due to high amount of external stimuli that affected the experiment.

Factor 1	Factor 2	Correlation coeff
Harmlessness	Walking	-0.63
Extraversion	CoP F Trial	-0.62
Extraversion	CoP F Exp02	-0.66
Extraversion	CoP F Exp03	-0.71
Extraversion	CoP Exp01	-0.66
Extraversion	CoP Exp02	-0.73
Extraversion	CoP Exp03	-0.82
Conscientiousness	EBD diff Exp02	0.64
Conscientiousness	EBD diff Exp03	0.61
Cuff frq diff Exp01	Wins Exp01	0.89
Cuff frq diff Exp02	Wins Exp02	0.80
Cuff frq diff Exp03	Wins Exp03	0.75
CoP F Trial	PRV diff Trial	-0.65
CoP F Trial	PRV diff Exp01	-0.62
CoP F Trial	PRV diff Exp02	-0.63
CoP F Trial	PRV diff Exp03	-0.65
Torso dist	CoP F Trial	0.63
Torso dist	CoP F Exp01	0.69
Torso dist	CoP Trial	0.63
Torso dist	CoP Exp01	0.61

TABLE I: Factors with correlation coefficient > 0.6 and p-value < 0.05 .

- Extraversion has an inverse correlation with CoP F and CoP, indicating that more extrovert subjects tend to approach the robot from a closer distance, as well as keep the overall distance to the robot shorter;
- Conscientiousness has a positive correlation with EBD diff, indicating that subjects who are more self-disciplined have longer blinking duration during the action window;
- Cuff frq diff has a positive correlation with the number of games won, indicating that participants who have pressed the cuff more frequently during an action won a higher number of games;
- CoP F Trial has inverse correlation with PRV diff, indicating that the participants who approached the robot closer the first time, have higher PRV during the experiment;
- Torso dist and CoP F and CoP have positive correlation, indicating that participants who keep the robot closer to the torso approach the robot from a closer distance the first time, stay closer to the robot during the experiment.

PRV has been shown to be related to mental stress, where higher PRV (with respect to the baseline conditions) indicate higher mental stress [8]. EBR and EBD are related to mental load, with higher EBR and shorter EBD corresponding to higher mental load [9].

From Table I, we can observe interesting correlations between personality traits and distance from the robot. In particular, extrovert people seem to be likely approaching the robot closer with respect to introverts. Conscientiousness indicates the general self-discipline level of people, and our results show that more self-disciplined people tend to have longer EBD in the action window, which may indicate a decrease in the mental load when an action occurs.

We can also observe a general increase of PRV when the participant approaches the robot from a closer distance the first time. This would mean a general increase in mental stress if the robot is approached closer.

The distance between participant and robot also showed interesting positive correlation with the distance they keep

between the torso and the end-effector. This may mean that people who stay closer to the base of the robot also do not mind keeping a closer distance with the robot end-effector.

It is also interesting to note that people who perceive the robot as less harmful (more obedient) tend to walk less during the experiment. This may be due to the fact that the participants who felt better control over the robot did not feel the need of adapting to the motions of the robot by walking around, or vice-versa.

It is also interesting to note the correlation between the number of wins and the frequency of pressing the cuff in the action window. This relationship may indicate that participants who adjust to the game playing by releasing often the cuff have a finer control over the game.

IV. CONCLUSIONS AND FUTURE DEVELOPMENTS

In this study we were interested in analyzing the perceptions and state of humans with respect to an active direct physical interaction task with a robot, and results show that there are interesting correlations among factors derived from questionnaires with physiological and quantitative data measured from both the human and the robot.

In the next step we will analyze the remaining of the data, including the motion capture data, gaze direction and position, GSR, further analysis of PPG (e.g. spectral analysis). It would be also interesting to analyze other stimuli than the action force (e.g. game winning), as well as variations during the experiment and/or the action window itself. Classification and/or factor analysis on the data may also lead to interesting patterns and will be considered for further studies. Once we have a defined set of established factors, the next step will be the integration of these factors in the control of the robot.

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