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Collaborative Robots' Perceived Safety
CROPS

Deliverable 2.3: Metrics and robot scenarios – collaboration with the robot

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Authors: *Kristina Nikolovska, Kristina Rakinić, Luka Komidar, Matjaž Mihelj, Sebastjan Šlajpah*

University of Ljubljana Faculty of Electrical Engineering

Univerza v Ljubljani Filozofska fakulteta Oddelek za psihologijo

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Contents

1 Introduction

While the main aim of Experiment 1 (see Deliverable 1.4) was to assess the participants' perceived safety while observing the robot, the main goal of Experiment 2 was to assess the participants' perceived safety during collaboration with the robot in two typical collaborative scenarios. One collaborative scenario represented a simulation of an industrial environment (assembly of a small electronic device), and the other scenario was an imitation of a laboratory environment (testing the efficacy of an antibiotic by using the Kirby Bauer method). In this document, we describe the metrics used for assessing the participants' perceived safety during these two collaborative applications. In Experiment 2, we were planning to use self-report and physiological measures (skin conductance), but could actually use only self-report measures due to the COVID-19-related restrictions.

2 Metrics

2.1 Before the experiment

2.1.1 Demographic variables

The participants will report on their demographic characteristics: age, gender, level of education, employment status, and their profession.

2.1.2 The short version of the Big Five Inventory (BFI-K)

The BFI-K (Rammstedt & John, 2005) is a short version of the 44-item Big Five Inventory (BFI; John, Donahue, & Kentle, 1991) designed to assess the Big Five personality dimensions. We will use the Slovenian version of the BFI-K (Zager Kocjan, 2016), which has comparable psychometric characteristics to the original version of the BFI-K. We already used this measure in Experiment 1.

2.1.3 Robot Acceptance Scale

The Robot Acceptance Scale was used and tested already in Experiment 1. In Deliverable 1.2 this scale is described in greater detail. It consists of the following components (items):

- Anxiety ("When using such a robot at home or work, I would be afraid of doing harm by improper handling."),
- Attitudes towards technology ("Using such robots seems like a good idea to me."),
- Intention to use ("I would use such a robot at home or work."),
- Perceived Enjoyment ("I would feel comfortable using such a robot."),
- Perceived Ease of Use ("I do not think I would have a problem using such a robot."),
- Perceived usefulness ("Using such a robot would make it easier for me to work at home or work."), and
- Trust ("I would feel safe using such a robot.").

The items are rated on a 7-point Likert scale (1 – strongly disagree, 7 – strongly disagree).

We also added two simple Yes/No questions about previous experiences the participants had with such robot arms and with robots in general:

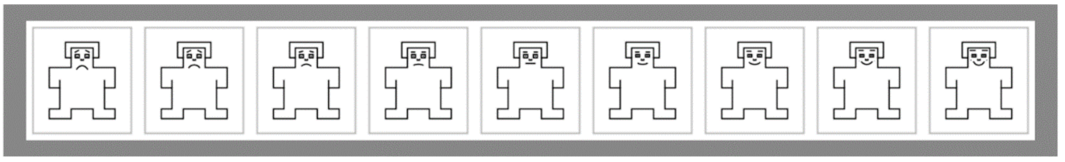
- Have you ever used such a robot arm at home or work?
- Have you ever used any kind of robot at home or work?
- If yes, which robot(s) have you used? (open-ended question)

2.2 During the experiment

2.2.1 Self-Assessment Manikin scale

The Self-Assessment Manikin (SAM; Bradley and Lang, 1994) is a non-verbal pictorial assessment technique that measures pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli. As in Experiment 1, we will use the first two items only (Figure 1) because dominance is not relevant to our study. We chose the version with nine pictograms. In our experiment, the participants will respond to different combinations of the robot arm movements and the tool the arm will be holding. Participants will need to choose the manikin that best represents their feeling when collaborating with a robot.

Item: *Pleasure*



Item: *Arousal*

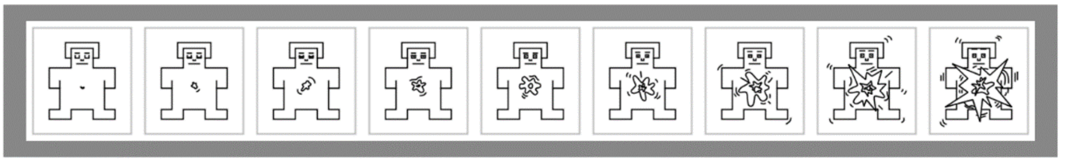


Figure 1: The 9-point Self-Assessment Manikins for measuring pleasure and arousal.

2.2.2 Perceived safety and intention to collaborate with the robot arm

During each trial of collaboration with a robot, the participants will respond on a 9-point Likert scale (1 – totally unsafe, 9 – totally safe) about their perceived safety of the robotic arm ("How safe did you find the robot movement?").

During each trial of collaboration with a robot, the participants will respond on a 9-point Likert scale (1 – not at all, 9 – most certainly) about their future intention to collaborate with the robotic arm ("To what extent would you in the future collaborate with a robot?").

2.3 After the experiment

2.3.1 Short debriefing

At the end of the experiment, participants will be asked to share their observations, thoughts, feelings about the experiment, and the movement of the robot. The researcher will write down their observations.

3 Experimental design of Experiment 2

With the Experiment 2 we wanted to assess perceived safety while the test subject was collaborating with the robot. As the experiment included two different applications we had to design special peripherals to enable easy transition between applications and thus further emphasise flexibility of collaborative robots. In collaboration, a human operator works in the close vicinity of the robot so special care was taken to provide a safe environment for the participants.

3.1 Experimental setup

Experimental setup included robotic arm UR5e from Universal Robots mounted on a table designed from an extruded aluminium, gripper Hand-E from Robotiq with specially designed fingers that enabled safe grip of all four tools (small box with the electronic circuit, the cover of the box, petri dish, testing leads, and pipette), peripherals designed to accommodate workpieces from both applications (workspace and buffer part holders, tool holders) human-robot interfaces (confirm buttons, signal lights), and safety sensors. Experimental setup can be seen in Figure 2.

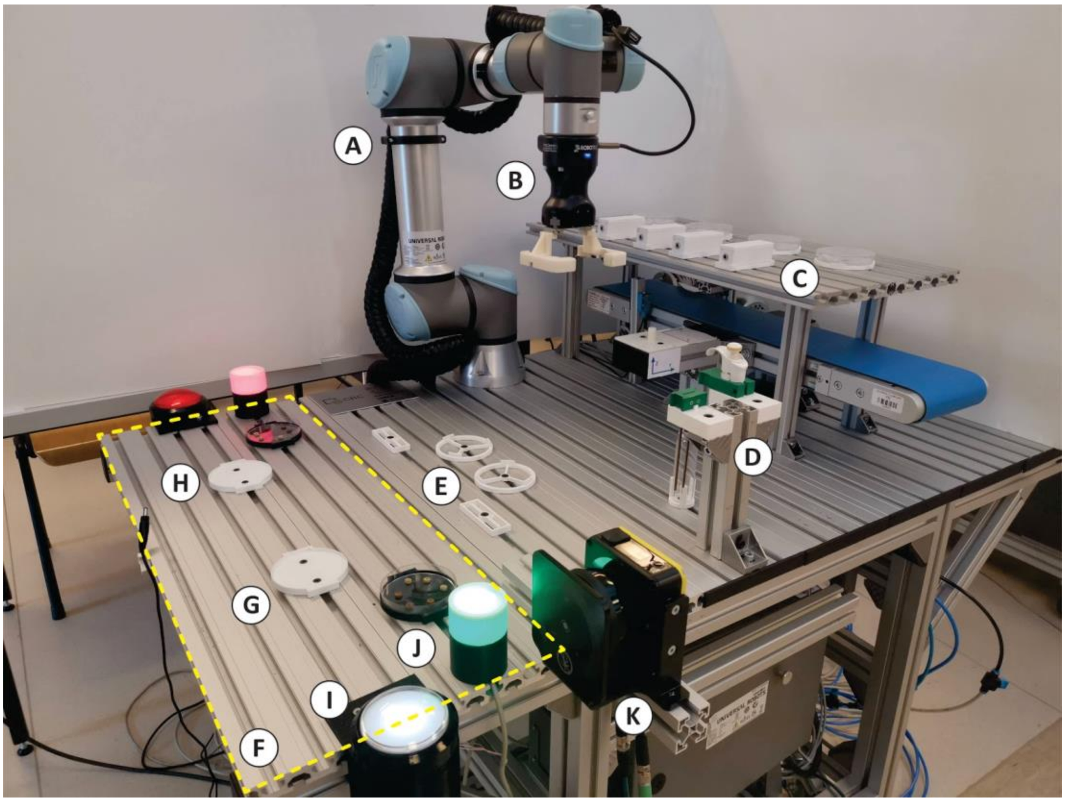


Figure 2: Experimental setup for both applications.

The main parts of the experimental robotic cell are as follows (see Figure 2):

A. collaborative robot Universal Robot UR5e;
B. gripper Robotiq Hand-E with 3D printed fingers;
C. holders for unfinished and finished parts for both applications;
D. holder for testing leads and pipette;
E. intermediate holders;

F. joined workspace;
G. workspace 1;
H. workspace 2;
I. confirm button;
J. signal lights;
K. safety sensor SICK NanoScan3.

Participant was seated on a movable chair so that he/she can freely move between two workspaces (left and right). Two buttons placed left and right from the participants were used for participants to confirm the finish of his/her part of the task. Buttons were also equipped with integrated light; blinking light was indicating that the user needs to finish his/her part of the task and confirm it by pressing the button. Signal lights were used to indicate the state of the robot:

- green light: user can work on the workpiece;
- yellow light: robot is coming to the workspace, be alert;
- red light: robot is working on the workspace, stay away.

Safety sensor SICK NanoScan3 was used as a safety light curtain. If the participants reached over the joined workspace, the robot entered reduced mode, i.e., lowered velocity of the movement and set stricter safety conditions of the system. As additional safety precautions, the robot's velocity in the joined workspace was hardcoded to 200 mm/s regardless of the velocity being tested.

3.2 Collaborative applications

For testing purposes two collaborative applications were developed. The first one was mimicking the industrial environment while the second was demonstrating the use of the robot outside the industry. Applications were designed in a way that the robot handled two workspaces simultaneously in parallel with the human operator. Overall four final products were produced with one set of experimental parameters.

3.2.1 Collaborative assembly of small electronic device

The product of this application was a finished box with inserted electronics, connected with wires to a pre-mounted power jack on the box, and cables connected to the electronics and directed through the cut on the box.

Robotic arm gripped the prepared box with the inserted electronics and transferred it to workspace 1. After that the robot uncovered the box and put the cover to the appropriate intermediate holder. At that point the signal light at workspace 1 turned green indicating to the operator that the workpiece is ready.

Operator inserted two wires to the push-in connectors on the board, pushed the ribbon cable through the cut on the box and connected it to the circuit board. At the end the operator checked the power on the board by plugging in 24 V power and inspecting the power lead on the board. If there were no problems, the operator confirmed the finished task by pressing the confirm button. In parallel, the robot prepared the second workspace.

When the operator was working on the part on the second workspace, the robot gripped the testing leads with pogo pins and tested the circuit on predefined test points as seen in Figure 3. While testing, the signal light was red which turned green when the test was finished.

At that point the operator inserted the QC mark onto the circuit and confirmed the action by pressing the confirm button. In parallel the robot tested the circuit on the workspace 2.

While the operator was working on workspace 2, the robot transferred the cover on the box and removed the finished box to the initial position. After that a new box was placed in an empty workspace.

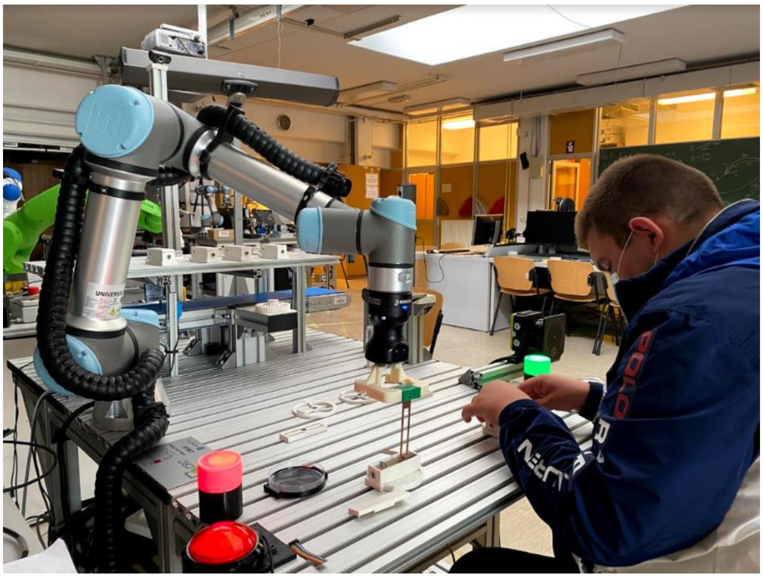


Figure 3: Operator assembling a small electronic device while the robot was testing the circuit in parallel.

3.2.2 Collaborative sample preparation for testing the antibiotics efficacy

The products of this non-industrial application were prepared tests for assessing the efficacy of antibiotics by using the Kirby Bauer method. Petri dishes were smeared with bacteria to prepare a lawn of bacteria. After that a filter paper discs with antibiotic dilution of different concentrations were introduced.

Robotic arm transferred an empty petri dish from the buffer holder to workspace 1 and removed the cover. After that the arm went for the second petri dish for workspace 2. The signal light on workspace 1 turned green indicating the user that workspace 1 is safe to operate.

The operator took a sample and smeared bacterial culture on the plate to create a lawn of bacteria using a sterile cotton swab. He/she confirmed the finished task by pressing the confirm button. During this operation the robot prepared an empty petri dish at workspace 2.

In the next step the robot picked up a pipette, filled it up with a prepared antibiotic dilution, and soaked the filter paper discs at workspace 1. During this operation the signal light was red.

When the robot moved away from workspace 1, the signal light turned green. Then the operator transferred filter paper discs onto marked spots on the petri dish with the bacterial culture as seen in Figure 4. After all the discs were transferred, the operator confirmed the finished action by pressing the confirm button.

At the end the robot picked up the cover and put it on the petri dish, and transferred the finished sample to the initial holder. After that a new empty petri dish was prepared.

Figure 4: Operator placing filter paper discs on the petri dish white the robot is preparing a new batch of paper discs soaked with antibiotic dilution.

3.3 Experimental protocol

All measurements took place at the Faculty of Electrical Engineering, University of Ljubljana, in the Laboratory of Robotics. Participants were asked to come to the faculty. They were accepted by the executive researchers. First, the researchers explained to the participants the purpose of the study. Before starting, the participants read and signed the informed consent that was necessary for participation in the study. The participants also filled in their demographic data. This part of the procedure took about 10 minutes.

Participants were asked to sit down at a table, which was their working space. There was also a robot on the table and all the work tools. On the left side of the working area sat a researcher who operated the robot, and on the right a researcher from the Department of Psychology, who was writing down the participants' answers about their feelings. An electrical engineering student also participated in the experiment, helping to prepare work aids. Participants were first briefly introduced to the course of the experiment. They were told that they would participate in two work scenarios, one imitating the industrial environment and the other the laboratory environment. Within these situations, they will perform different steps of the task, and after each trial, they will report about their level of pleasure and arousal, how safe they found the robot's movement to be, and to what extent they would be willing to work with the robot in the future.

Participants then began the experiment with an industrial or laboratory scenario. The researcher first explained to them all five steps of each scenario. Participants had a trial practice without the robot before each scenario to familiarize themselves with the workflow. Each of the five steps of the applications was a different combination of velocity and tool. The combinations used in the experiment are presented in Table 1. Before each condition, the researcher once again explained to the participants the course of the task so that the participants knew what the robot would do and what their task was. This part of the experiment in average took half an hour.

Table 1: Possible combinations of application type, tool, and velocity used during experiment.

Combination	Application	Tool	Velocity [m/s]
1	Industrial app	safe	0.3
2	Industrial app	dangerous	0.3
3	Industrial app	safe and dangerous tool	0.3
4	Industrial app	safe	0.75
5	Industrial app	dangerous	0.75
6	Industrial app	safe and dangerous tool	0.75
7	Laboratory app	safe	0.3
8	Laboratory app	dangerous	0.3
9	Laboratory app	safe and dangerous tool	0.3
10	Laboratory app	safe	0.75
11	Laboratory app	dangerous	0.75
12	Laboratory app	safe and dangerous tool	0.75

After the experiment, participants were asked to share observations, feelings and experiences they had during the experiment. The executive researcher from the Department of Psychology wrote down their observations. The executive researchers thanked the participants for their time and cooperation and accompanied them from the faculty.

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