Instructions for Study on Physical Human-Robot Interaction – FlexIRob@Harting

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A common problem for human-robot collaboration in confined spaces is the poor local situational awareness of the human operator on the position of each manipulator joint. To handle this problem we propose to decompose teaching of a redundant industrial robot into a task independent and a task dependent part. The task independent part focuses on conveying the constraints of a working environment. The human tutor can concentrate on controlling the robot joints without being disturbed by the concrete task. During the task dependent part the robot is taught-in a specific task, e.g., a trajectory, just by controlling the end-effector. The joints are controlled by the robot utilizing the provided information about the environmental constraints.

In this section we present our user study designed to evaluate this decomposition of a robot-tutoring in a physical human-robot interaction task. In particular, we are interested in analyzing whether our approach is intuitive and comfortable for naive users, how exhaustive the work with the robot arm is, whether the task independent robot reconfiguration is partable, how well and how fast can it be done, and what are the characteristics of the training data showing provided by the naive users to the system.

According to the proposed decomposition of robot-tutoring-tasks into a task independent and a task dependent part our study consists of two main parts representing this splitting. The first part concentrates on teaching the robot valid joint configurations in a constrained environment without an application in mind. The second part deals with a teach-in of a concrete task in this environment. As industrial tasks often require that a robot arm is able to follow a demonstrated trajectory, we let them play a variant of the wire-loop game to simulated this ability. There, the study participant had to demonstrate through kinesthetic teaching a trajectory along a parcour placed in the previous introduced constrained working space. To test the hypothesis that robot-assistance for controlling the position of the joints (here called assisted gravity compensation mode) reduces the task complexity significantly, we have divided our study participants into two groups. Group A, the assisted group, was supported by the assisted gravity compensation mode. They just needed to guide the end-effector. Group N was not assisted by the robot. They needed to watch out for all joints and the end-effector simultaneously in order to avoid collisions with the environment and to complete the task. In the following, the detailed procedure of the study is outlined.

The experiment for each participant was divided into four main parts:

- a warm-up phase
- the task independent configuration phase (3 trials)
- the wire-loop game
- the questionnaire.

Participants were welcomed and given an overview over the procedure:

Hello and thanks for your participation in the study. I am (NAME) and I guide you through the study, this is (NAME) and this is (NAME), they are responsible for the technics during the procedure. This is the robot you are going to work with. The goal is that it will be able to support you during your work in a few years, like transmitting you things and by that easing your tasks. It is possible to prevent spinal and back disorders because of bad positions.
The robot is able to adapt to any work spaces through learning, you can move it fast from one to another workspace. The course of action will be that you at first have a little warm-up to make you familiar with the robot, after that we will ask you about your first impressions. After that we continue with the main task, in which you are supposed to teach the robot a workspace with obstacles. Finally you will receive another questionnaire to cover your opinion. Till now, do you have any questions?

If participants had no more questions they were asked to sign an informed consent and a consent form for recording and later usage of the video data. This was completely voluntary and could be negated. After that the warm-up was started.

Okay if there are no more questions we will start with the warm-up, during which you are supposed to acquaint yourself with the robot. Please take a look at this video. It shows how the arm can be moved.

During the video participants were shown how all seven joints could be moved and how the arm could be moved into different positions. They were informed about the two different operational modes of the robot system (gravity compensation and joint impedance) and the switch between these two modes. They were told that they could not damage anything and could safely touch the robots’ gripper to make sure they felt no inhibitions to handle the robot. After the video was finished participants were instructed to try out the robot get used to the handling of the seven joints. More specifically, they were instructed to reproduce what they saw in the video. Depending on what participants tried out on their own they were encouraged to try both operational modi and different movements, to make sure that they were prepared for the following task. After participants had finished the warmup, the second task was announced. During the reconfiguration phase an exemplary working place with a constrained working space for the robot was built up and the participant was asked to train valid postures to the FlexIRob system according to this constrained working space:

Now we will start the learning task. As you already heard the robot is able to learn different work spaces. Here, you see an example of a work space with different obstacles [point at obstacles]. The robot is supposed to avoid them during his work. You can teach this to it. It is of great importance, that neither you nor the robot touches the obstacle during the teaching. We will repeat the task three times. The teaching works as follows: At first you move the robot to the left working space. When it has reached the boxes you make a short pause to indicate that the goal is reached. The robot confirms with a peep. Then, like during the warmup, you do a helix with a diameter of about 10cm above the boxes to teach this work space. When it is ready for the next action it will peep again. Then you move it to the right work space, wait again until goal reaching is noticed, and then do a helix again. When you are finished we give (NAME) a sign. Afterwards, always take one step back from the robot. When the robot learned both work spaces we will see whether it understood the work space correctly and avoids the obstacles. Any questions?

To see how much instruction participants need to complete the task without errors escalating instructions were given. The hints were chosen in way that with ongoing trials the possibilities moving the robot from one working area to the other are more and more restricted and thus should help the participants to find a ‘valid solution’:

1. trial:
The robot works in two work spaces [show spaces] and moves between them. Please consider this during the teaching.

https://www.cor-lab.de/system/files/Instruktion.mp4
2. trial:
This is the working space [show space], the robot should not leave this space with
the gripper. Please consider this during the teaching.
(The difference to the first instruction is that the whole exemplary work space was
shown, not only the two boxes on the left and on the right.)

3. trial:
The gripper is always supposed to point down and should make a straight line between
both work spaces. Please consider this during the teaching.

After each try the participant was told to step back from the robot. Then he was
explained that the robot processed the data and that the result of the training was
supposed to be seen after that. Once the system was trained, a reference movement
(a straight line) was performed by the robot arm from the left to the right training
area. The task was then repeated and the next instruction was given.

The last part of the study is the wire-loop game. Participants were asked to play
a variation of the wire-loop game. The task was to move the robot with the gripper
along a given show-jumping course while respecting the constrained working space.
This game should simulate a teach-in of a concrete task to the robot. During this task
the experimental manipulation took place. Participants were instructed as follows:

Thanks, we will go on with the last task. You are supposed to play a game like the buzz
wire game with the robot (Original game was explained if participants did not know the game)
and guide it along a structure of Styrofoam. (NAME) will set it up now. The goal is to
teach the robot the exact course of the Styrofoam.

Then participants got different instructions regarding condition. The first group had
to perform the task in gravity compensation mode which means that they had no
assistance by the system. Hence, they had to take care of all the joints in order to not
collide with the obstacles in the environment on the one hand and on the other hand
had to perform the task (wire-loop game) as accurate as possible. The second group
was using the assisted gravity compensation mode meaning that the user leads the
robot only by moving the gripper whereas the respective joint configuration to reach
this user defined end-effector position was controlled by our system with a network
trained specifically to the current environment. Hence, the user could concentrate on
fulfilling the task (wire-loop game) while the robot automatically respects its envi-
ronment. Participants were randomly assigned to one of the two groups and instructed
as follows:

Assisted group:
It is your goal to guide the robot along the styrofoam without touching it and without knocking
over the obstacles. The robot exactly repeats what you show it. To show it the way simply
guide it along the Styrofoam by holding the gripper. You start on the left, guide it to
the right and then back to the start. [show the way]

Non-assisted group:
It is your goal to guide the robot along the styrofoam without touching it and without knocking
over the obstacles. The robot exactly repeats what you show it. To show it the way simply
guide it along the Styrofoam. You start on the left, guide it to the right and then back
to the start. [show the way]

After the teach-in participants were told to step back and watch how well the teach-in
worked. The robot then exactly copied the way the participants guided it. Then they
were told that they were about finished and were given the questionnaire. Participants
that obviously did not understand the questionnaire or asked for help to fill it in were interviewed. That case occurred twice during the experiment. Participants were instructed how they were supposed to fill in the questionnaire and were given a short overview over the different topics. They were instructed to ask if there were any questions they did not understand.

The questionnaire has been designed specifically for the scenario used in the study. It has been adapted to the tasks and to the specific demographic background of participants. Characteristics of the sample included the educational background and the fact that some employees were no German native speakers. Therefore it is necessary to adapt the questionnaire for other scenarios and samples. The questions were derived from expert-discussions and pre-tested with 4 students from Bielefeld University. Due to the characteristics of the sample all questions were discussed with a member of the staff of Harting. Items that were expected not to be understandable were changed or removed. The resulting questionnaire contains 36 questions structured into 7 topics dealing with:

- the general experience with the robot during the interaction
- the wire-loop game
- whether or not participants could imagine the robot to support them during various tasks
- Demographic variables
- Other control variables (e.g. stereoscopic vision)
- Previous experience with robots
- Suggestions/ ideas for improvement

The items concerning general experience with the robot and the wire-loop game covered important characteristics of the robot like threat, reliability and intelligence and characteristics of the handling like ease, pleasantness, cognitive load during handling etc. All items concerning robot and task were rated on a five-point Likert scale ranging from 1 (yes/very much) to 5 (no/not at all). All items covering previous experience, support by the robot and control variables were rated on a three-point Likert scale ranging from 1 (yes/very much) to 3 (no/not at all). This reduction of dimensions was used to facilitate the completion of the questionnaire. The questionnaire in German is available here.

After the completion of the questionnaire participants were debriefed, thanked and dismissed. To keep the conditions and instructions stable through the whole experiment a sheet of valid instructions was complied. Each conductor of the study ran adhered to the guidelines.

[https://www.cor-lab.de/system/files/FragebogenHartingstudy.pdf](https://www.cor-lab.de/system/files/FragebogenHartingstudy.pdf)