End-User Robot Programming Case Study: Augmented Reality vs. Teach Pendant

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ABSTRACT

The work presents a preliminary experiment aimed for comparing a traditional method of programming an industrial collaborative robot using a teach pendant, with a novel method based on augmented reality and interaction on a high-level of abstraction. In the experiment, three participants programmed a visual inspection task. Subjective and objective metrics are reported as well as selected usability-related issues of both interfaces. The main purpose of the experiment was to get initial insight into the problematic of comparing highly different user interfaces and to provide a basis for a more rigorous comparison, that is going to be taken out.

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1 INTRODUCTION

With novel and unusual interfaces and interaction methods, a significant problem emerges: how to compare it with existing and well-known methods or interfaces. While comparing partial interfaces' features might be easy and intuitive, comparing two complex and highly different systems is challenging in terms of experiment design and evaluation of the results. Although experiments with novel interfaces could provide good insight into whether the interface is usable by measuring subjective data, a fair comparison with existing method is crucial for measuring improvements in e.g. efficiency, in order to provide justification that the new method offers added value over the existing one and could be successfully deployed in the real-world industrial settings.

Several experiments were conducted to evaluate usability of our augmented reality (AR) interface ARCOR for end-user robot programming [1, 5, 6]. This interface allows user to program the robot using highly abstracted instructions such as *PickFromTable*, *DrillHole*, etc., using a user-friendly graphical interface projected on a touch-enabled table. Although the interface was evaluated several times, no comparison with any existing method took place yet, as our system did not support any standard industrial robotic arm. Recently, support for Aubo i5 robotic arm was added. This paper presents preliminary experiment designed as a case study aimed to get the insight into comparing such different interfaces.

Figure 1: Participant programs a visual inspection task using the ARCOR spatial augmented reality interface.

2 BACKGROUND

The traditional method of programming industrial robots is through the teach pendant. There exist various pendant interfaces. Some of them, as ABB FlexPendant with its text-based programming, are targeted to expert users, while others are more suited for less skilled users as Universal Robots Polyscope with its tree-based program visualization and wizards. Emerging alternative methods aimed on simplification of the robot programming for non-experts were so far often not evaluated with a (user-friendly) pendant as a baseline method. There exist only few examples of evaluations, where such comparison have been carried out. However, the published experiments have various limitations. For instance, [7, 10] were carried out with only one pendant-expert user and [11] was carried out in a simulation. The experiment in [3] seems well designed, with sufficient number of participants, however only with a simple pick and place task. Existing experiments are usually designed ad hoc, as there is a lack of proven methodology. For instance, method to compare HRI approaches is proposed in [8], however extension beyond trajectory teaching task would be needed.

3 EXPERIMENT DESIGN

A preliminary 2-condition within-groups case study was conducted. The main goal of presented case study was to verify, that the proposed method of simplified robot programming is suitable for a visual inspection task and performs better than the teach pendant (which interface is similar to UR Polyscope). The robot is instructed to pick the bottle opener from the table, put it in front of the camera, trigger the inspection method and based on inspection result, put the bottle opener to one of the boxes on the table. In order to make the comparison more fair, a few high level functions as *pick*, *place* or *suction (on/off)* were prepared in advance in pendant. The experiment was conducted with 3 participants (2 males and 1 female), in a lab-like environment. All of the participants had little

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Participant	A_p	A_a	B_p	B_a	C_p	C_a
Introduction [s]	359	179	449	311	185	174
Task [s]	562	189	749	309	510	146
TLX [0, 100]	72.22	36.11	44.44	27.78	33.33	19.44
SUS [0, 100]	52.50	82.50	42.50	80.00	70.00	90.00
UEQ_{ATT} [−3, 3]	−1.17	2.00	−0.17	1.83	1.83	2.50
UEQ_{PRA} [−3, 3]	0.25	2.08	−0.50	1.83	1.58	2.25
UEQ_{HED} [−3, 3]	−0.25	2.12	−1.25	1.62	0.25	2.00

Table 1: Durations of introduction and programming for both (p)endant and (a)rcor modality. Subjective metrics for each participant and both modalities. Higher means better for all subjective metrics except TLX.

or no prior experience with AR, participants A and B had little or no prior experience with teach pendant while participant C had moderate prior experience with pendant.

The experiment involved two sessions (first with pendant, second with ARCOR) consisting of training and programming the actual task. Each of the sessions was followed by filling in the standard questionnaires [2, 4, 9] and discussion. Participants were recorded using standard camera for future analysis. Moreover, several physiological data were recorded using the Empatica E4 wristband.

4 RESULTS

All participants were able to complete the task using both methods (teach pendant, ARCOR). For each participant, the time needed for both introduction and programming itself was lower for ARCOR interface (see Table 1). The ARCOR also performed better in terms of usability, UX and task load metrics. Detailed cases for each participant follows.

4.1 Participant A (25, male, programmer)

While using the pendant, the moderator had to intervene approximately 8 times, to help the participant to overcome the issues with the pendant interface, mainly finding the right buttons for desired task. Participant was a bit frustrated when he wanted to copy block of instructions, which was not possible.

With ARCOR, only one intervention of the moderator was necessary, when the participant overlooked the dialog for saving the robot position. Sometimes, the participant was unsure, what is the next required step, but he was always able to resolve this uncertainty using the notification area of the interface. The participant complained about the positioning of some GUI elements, which were sometimes hidden by real objects.

Overall, the participant considers the teach pendant too complicated, slow and cumbersome. He prefers the ARCOR interface more, because a lot of things are already prepared in advance and it allows him to focus on the programming itself.

4.2 Participant B (41, male, application tester)

With the pendant, the participant struggled with the complex GUI: there were difficulties in finding buttons, instructions and instruction lists. This was the main cause of frequent moderator's interventions. Moreover, the participant asked the moderator several times, whether is he proceeding correctly in setting individual instructions and waypoints.

When the participant was using the ARCOR interface, there were significantly less moderator's interventions, related only to the touch surface problems (e.g. non-registered touches). The participant was able to successfully use the notification area of the interface when felt lost or didn't knew how to proceed further.

Although the participant preferred, based on the results, the ARCOR interface better, there were some complaints about setting the box location area, where the interface could be more automated and, for example, not allowing the user to move the UI elements off the touch-enabled surface.

The participant considered the pendant approach difficult, but admitted that it could be learned if there is no other option.

4.3 Participant C (23, female, programmer)

The prior experience with pendant of this participant is reflected by the lowest time needed for introduction to this modality and could explain better score in all measured metrics in compare to other participants. However, she still ranked the ARCOR modality better in all metrics. Despite the prior experience, the participant was insecure at the beginning and was using quite a big amount of help from the moderator. After few minutes however, she became more certain about various elements of the interface.

For this participant, setting the position of the robot was physically challenging, which could be one of the reasons why ARCOR interface was ranked better, as it requires less direct manipulation with the robot.

The participant had no fundamental problem with ARCOR interface, she only suffered from some design issues like ambiguous buttons, visualization of inactive buttons or slow response from the system, where she was uncertain whether e.g. some button was successfully pressed.

She felt good using both interfaces, but she considered the ARCOR interface simpler and faster.

5 CONCLUSIONS

The conducted preliminary experiment was focused on comparing two highly different methods of robot programming: spatial augmented reality and user-friendly teach pendant. It was necessary to deal with different complexity, level of abstraction (high for AR, low for pendant) and specifics of each method. The results indicate the potential of the ARCOR system, which was preferred by the participants over the pendant and also required less time to train as well as to program the visual inspection task. The upcoming experiment will involve more participants in order to enable statistical analysis of the results, contain various tasks in order to provide more generalizable results and will be performed out of the lab. Moreover, more high-level functions for the pendant will be prepared in advance, in order to improve the fairness of the comparison. Also, the pendant modality will require a more complex training procedure. Gained experience will allow us to formulate an exact methodology for this kind of experiments.

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