Features of Interaction Between a Human and a Gestures-controlled Collaborative Robot in an Assembly Task: Pilot Experiments

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Abstract

This paper presents results of pilot experiments that were run to study a human interaction with the UR5e collaborative 6-axis robot manipulator in a cooperative assembly task. The participants controlled the equipped with a screwdriver UR5e robot using computer vision and gestures. The purpose of the experiments was to identify the features of user interaction with the UR5e robot controlled with gestures in a task of a complex object assembly. Ten people took part in the experiments. The results of the experiments allowed to conclude on practical efficiency of cobots in joint assembly tasks. In addition, we identified preferable by the users location areas during the assembly task.

Keywords: Human–robot interaction, Human-robot collaboration, Collaborative robots, Collaborative Assembly

1. Introduction

Due to a significant progress of industrial automation, issues of human-robot interaction in a shared workspace[1] and efficient distribution of collaborative tasks between human and robotic agents[2] became critical in the past decades. In practice, a human-robot collaborative assembly task often arises in cases where a part of assembly process stages requires a human intervention[3]. An example is a situation when a part of assembly operations cannot be automated, or full automation of operations is impractical due to a high cost and complexity of a setup process. Of particular interest are cases in which human operations with assembly parts alternate with actions of a robot. In this case, the operator interacts with the robot through various communication technologies.

A positive user experience (UX) in human-robot interaction (HRI) is essential for an efficient organization of human-robot production processes. Despite a significant number of studies devoted to a methodology for assessing the UX in social robotics, a problem of choosing certain methods for assessing UX of a human-robot collaboration remains open[4].

Communication between humans and robots can take both verbal and non-verbal forms[5]. In practice, multi-modal interfaces can be used to communicate with industrial robots, including buttons and joysticks, a haptic control, speech recognition technologies, a gesture control, and a gaze recognition[6].

Specifics of a particular manufacturing process may impose some restrictions on the human-robot interaction. For example, tactile and button controls can distract an operator from an assembly process, and noise in a manufacturing area can prevent successful recognition of voice commands. In this case, an interaction with the robot through gestures seems to be the most convenient.

In this paper, we present results of pilot experiments that were run to study a human interaction with the UR5e collaborative 6-axis robot manipulator in a cooperative assembly task. Our study is aimed at identifying features of a user interaction with the gesture-controlled robot during the joint assembly task in order to further apply the results in practice when designing real manufacturing processes.

2. Related work

Collaborative robots are often considered safer for humans than industrial robots[7]. A number of review papers were devoted to a collaborative assembly implementation[8][9]. Papers[10][11][12] considered various aspects of the methodology for designing and implementing HRI in the context of assembly tasks.

Holm et al.[13] presented the results of an evaluation of a human-robot interaction at three industrial demonstrators: Mixed Packaging of Cheese, Aircraft Wing Rib Assembly and Automotive Engine Mass Balancing System Assembly. In [14] and [15], an influence of cognitive ergonomics on the interaction between a human and an industrial robot during a joint assembly was investigated. Neto et al. [16] proposed a gesture-based HRI structure in which a robot helps a person by passing tools and parts. Paper [17] presented the results of experiments with a collaborative robot controlled by gestures. For the gestures classification a taxonomy proposed in [18] was used.

Taking into account the literature review we focused on the following aspects in the course of preparing pilot experiments:

- Safety;
- Qualitative and quantitative evaluation of the human-robot interaction;
- Ergonomic requirements for the workspace.

3. Materials and methods

3.1. *Participants*

The experiments involved 10 people who are not professional operators of collaborative industrial robots. To guarantee an independent nature of the experiments the participants did not contact with each other during the experiment.

3.2. *Assembly task and workcell configuration*

During the experiment, participants were asked to assemble a chassis of a small mobile robot. The chassis consisted of several parts that should be fastened with screws. The experimental workcell (Fig. 1) included:

- UR5e robot equipped with a screwdriver;
- a work table;
- a camera for tracking the operator's movement within a danger zone;
- a camera for a gesture recognition;
- a screen for displaying information for the operator;
- a chair for the operator.

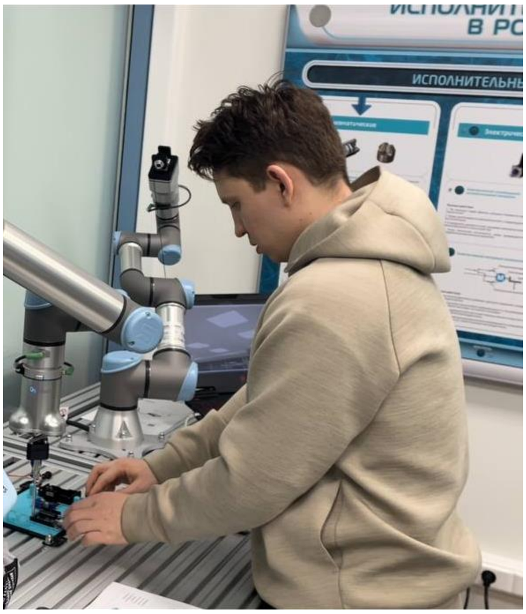

Fig. 1 The workcell during the experiment

3.3. *Experimental protocol*

The experiment consisted of three stages. At the first stage, the participants were trained to control the UR5e robot using predefined gestures. This stage was necessary in order to get acquainted with the system of robot control gestures. The set of gestures used consisted of symbols A, B, C of the American sign language ASL[19]: A was for power on of the UR5e robot, B was for playing or continuing the robot program, C was for pausing the program (Fig. 2). Participants also had an opportunity to test a safety system, which stopped the robot if the participant's hand entered a working area of the robot.

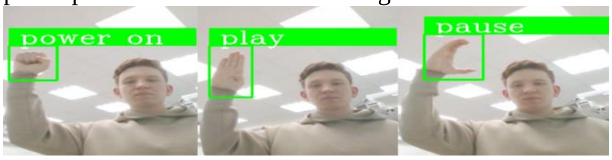

Fig. 2 The view from a camera for the gesture recognition. The participant shows gestures (from left to right): power on, play or continue the program, pause the program

At the second stage, the participant was asked to assemble the chassis manually (without the robot assistance) according to provided instructions.

At the third stage, the participants assembled the same chassis together with the robot. This stage was organized as follows. The participant placed several assembly parts on the chassis platform and passed them to the robot for tightening (Fig. 1) the screws. After the robot fixed the current parts on the platform, the participant placed new parts on the platform and again transferred the platform to the robot.

After the experiment, the participants were asked to take a survey that consisted of the following questions:

Q1: Was it easier for you to assembly the chassis with the UR5e robot assistance than without the robot?

Q2: How accurately did the UR5e robot execute commands based on your gestures?

Q3: How quickly did the UR5e robot respond to your commands?

Q4: How comfortable were you working with the UR5e robot?

Q5: How good did the UR5e robot perform its task?

Q6: What disadvantages in the robot operation could you note (if any)?

Q7: What gestures would you prefer to use?

We used a 5-point Likert-type scale [20] for questions Q1-Q5 and a free form for questions Q6 and Q7.

4. Results

Fig. 3 presents survey results (Q1-Q5). The x-axis (horizontal axis) indicates a question number. The y-axis (vertical axis) indicates a number of responses of participants for a particular answer to the questions (e.g., in the first question seven participants chose the forth answer option). A legend on the right side of the graph is indicates which color of the graph corresponds to a certain answer option in the questions. In general, the participants expressed satisfaction with both the work of the robot itself and the level of the comfort. However, two (of ten) participants noted that self-assembly of the chassis without a robot seemed faster to them.

In response to question Q6 two participants indicated the slow screw tightening by the robot, two participants noted the need to provide a more explicit feedback from the robot, e.g., with voice messages.

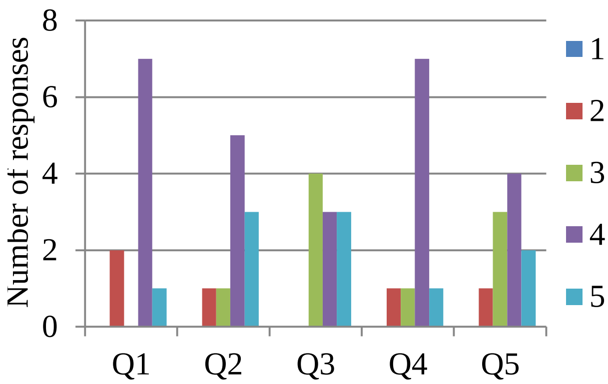

Fig. 3 The survey results. Avg: Q1 - 3.7, Q2 - 4.0, Q3 - 3.9, Q4 - 3.8, Q5 - 3.7

In response to question Q7, two participants suggested using gesture A to stop and gesture B to continue. Five participants indicated that gesture C was inconvenient to use. One participant suggested using gestures with one and two fingers instead of gestures A and B, respectively. The rest of the participants noted that all gestures were comfortable for them.

In the area of the workcell we placed a chair for the operator. Before the experiment, we informed each participant that he/she could sit or stand as desired. We observed that all participants periodically changed standing and sitting positions.

5. Discussion and conclusions

The conducted pilot experiments allowed us to formulate some hypotheses about the features of the user interaction with the gesture-controlled robot UR5e in the context of collaborative assembly.

The first hypothesis suggests to review the choice of the robot control gestures. We intentionally avoided using special gestures' sets for industrial robot control from a literature review (e.g., [21]) in order to test whether users could quickly adapt to gestures with an unusual semantic load. We noted that after the training phase, despite the fact that all users correctly used all gestures, some of them indicated their preferences. It can be assumed that in order to improve perception during the learning phase, along with the default gesture system, users should be prompted to select their own gesture system.

The second hypothesis relates to the speed of the robot's screw tightening actions. In our experiments, due to peculiarities of the end-effector, the robot performed the tightening rather slowly. This could negatively affect the perception of the robot efficiency by users. We assume that when using an automatic screwdriver end-effector and increasing the tightening rate, the negative estimates associated with the tightening rate would be leveled.

The third hypothesis concerns the operator position during the experiment in order to reduce a biomechanical load on the operator. In our experiments, the working surface on which the assembly parts were located allowed the operator to perform his/her work both sitting and standing. Most of the participants selected a sitting position during those stages of the experiment when the robot performed operations that did not require a human intervention and stood up when their intervention was required. Perhaps most users would prefer to do all work in a sitting position, if conditions of the work cell allow it. In addition, we concluded that the location of the camera that reads gestures should take into account the operator height in order to reduce the biomechanical load on his/her hands when showing the gestures.

The results of our experiments demonstrated that the use of the UR5e assisting robot for collaborative assembly tasks could be effective from a practical point of view. In our further studies, we plan to test the hypotheses we have put forward, as well as the degree of influence of the interaction features we have identified on the efficiency of the assembly process as a whole.

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References

1. Galin R, Meshcheryakov R. Review on human–robot interaction during collaboration in a shared workspace[C]//International Conference on Interactive Collaborative Robotics, 2019: 63-74.
2. Galin R, Meshcheryakov R, Kamesheva S. Distributing tasks in multi-agent robotic system for human-robot interaction applications[C]//Int. Conf. on Interactive Collaborative Robotics, 2020: 99-106.
3. Villani V et al. Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications[J]. Mechatronics. ScienceDirect, 2018, 55: 248-266.
4. Lindblom J, Alenljung B, Billing E. Evaluating the User Experience of Human–Robot Interaction[J]. Human-Robot Interaction. Springer, 2020, 12: 231-256.
5. Mavridis N. A review of verbal and non-verbal human–robot interactive communication[J]. Robotics and Autonomous Systems. ScienceDirect, 2015, 63(1): 22-35.
6. Gustavsson P, Holm M, Syberfeldt A, Wang L. Human-robot collaboration – towards new metrics for selection of communication technologies[J]. Procedia CIRP. ScienceDirect, 2018, 72: 123-128.
7. Sultanov R, Sulaiman S, Li H, Meshcheryakov R, E Magid. A Review on Collaborative Robots in Industrial and Service Sectors[C]//Siberian Conference on Control and Communications, 2022 (in press).
8. Rodríguez-Guerra D, Sorrosal G, Cabanes I, Calleja C. Human-Robot Interaction Review: Challenges and Solutions for Modern Industrial Environments[J]. IEEE Access. IEEE, 2021, 9: 108557-108578.
9. Dobrokvashina A, Sulaiman S, Zagirov A, Chebotareva E, Hsia K-H, Magid E. Human Robot Interaction in Collaborative Manufacturing Scenarios: Prospective Cases[C]//Siberian Conference on Control and Communications, 2022 (in press).
10. Mateus J C, Claeys D, Limère V, Cottyn J, Aghezzaf E-H. A structured methodology for the design of a human-robot collaborative assembly workplace[J]. The International Journal of Advanced Manufacturing Technology, 2019, 102(5): 2663–2681.
11. Gualtieri L et al. Safety, Ergonomics and Efficiency in Human-Robot Collaborative Assembly: Design Guidelines and Requirements[J]. Procedia CIRP. ScienceDirect, 2020, 91: 367-372.
12. Colim A et al. Human-Centered Approach for the Design of a Collaborative Robotics Workstation[B].

Occupational and Environmental Safety and Health II. Springer, 2020, 277: 379-387.
13. Holm M et. al. Real-World Industrial Demonstrators on Human–Robot Collaborative Assembly[B]. Advanced Human- Robot Collaboration in Manufacturing. Springer, 2021: 413-438.
14. Gualtieri L, Fraboni F, Marchi M D, Rauch E. Evaluation of Variables of Cognitive Ergonomics in Industrial Human-Robot Collaborative Assembly Systems[C]//Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). Springer, 2021, 223: 266-273.
15. Fraboni F, Gualtieri L, Millo F, Marchi M, Pietrantoni L, Rauch E. Human-Robot Collaboration During Assembly Tasks: The Cognitive Effects of Collaborative Assembly Workstation Features[C]. Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021). Springer, 2021, 223: 242-249.
16. Neto P, Simão M, Mendes N, Safeea M. Gesture-based human-robot interaction for human assistance in manufacturing[J]. Int. J. Adv. Manuf. Technol. Springer, 2019, 101(1): 119–135.
17. Shukla D, Erkent Ö, Piater J. Learning Semantics of Gestural Instructions for Human-Robot Collaboration[J]. Frontiers in Neurorobotics. Frontiersin, 2018, 12: 7.
18. Quek F K H. Eyes in the interface[J]. Image and Vision Computing. ScienceDirect, 1995, 13: 511-525.
19. Wilbur R B, Nolkn S B. The Duration of Syllables in American Sign Language[J]. Lang speech. Sage journals, 1986, 29(3): 263-280.
20. Krägeloh C, Bharatharaj J, Kutty S K S, Nirmala P R, Huang L. Questionnaires to Measure Acceptability of Social Robots: A Critical Review[J]. Robotics. MDPI, 2019, 8(4): 88.
21. Shukla D, Erkent Ö, Piater J. A multi-view hand gesture RGB-D dataset for human-robot interaction scenarios[C]//25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN). IEEE, 2016: 1084-1091.

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