IOP Conference Series: Materials Science and Engineering

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To cite this article: Patrik Gustavsson and Anna Syberfeldt 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1063** 012010

IOP Conf. Series: Materials Science and Engineering 1063 (2021) 012010 doi:10.1088/1757-899X/1063/1/012010

The Industry's Perspective of Suitable Tasks for Human-Robot Collaboration in Assembly Manufacturing

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Abstract. Human-robot collaboration (HRC) is the concept of combining a human and a robot into the same production cell and utilize the benefits of both. This concept has existed for more than a decade, but there are still quite few implementations of HRC within the manufacturing industry. One reason for this is the lack of knowledge when it comes to suitable tasks for HRC. Current research studies on the topic are mainly based on theoretical reasoning and/or research experiments, and little is known about what the industry perceive as suitable tasks for HRC. Therefore, this paper aims to investigate this and find out what industrial actors thinks are the most value-adding tasks for a human and a robot to carry out together. An in-depth interview study is undertaken with two companies and shop-floor operators, production engineers and automation engineers are interviewed. The result of the study pinpoints a number of tasks that the companies thinks are beneficial for HRC, which can serve as a guideline for other manufacturing companies considering to implement HRC.

1. Introduction

Human-robot collaboration combines the strengths of both humans and robots into a hybrid production cell [1]. There are several application areas in which HRC are advantageous, of which assembly manufacturing is one of the major [2]. In current implementations of HRC there are, however, often a limited interaction between the human and the robot in order to ensure the safety of the human [3]. This is a drawback since to fully utilize the potential of HRC, the human and the robot should interact and not only work side-by-side or in sequence with each other. To realize work cells in which the human and the robot are truly working together with each other it must be known what tasks that are suitable for such collaboration. There are a number of research papers that presents studies on the topic, but these are mainly based on theoretical reasoning and/or research experiments that investigate the suitability of various tasks. There is not much knowledge about what manufacturing companies perceive as suitable tasks for HRC, and this paper therefore aims to address this question. The paper is specifically focused on assembly manufacturing as this is a main application area for HRC. An in-depth interview study is undertaken with one manufacturing company and one automation integrator company. In these companies, shop-floor operators, production engineers and automation engineers are asked to give their view on what they perceive as suitable tasks for HRC. The manufacturing company is a large company producing quick connect couplings having production sites in several different countries around the world. The study takes place in one of their sites where these couplings are assembled. The automation integrator company produces automation solutions for manufacturing industries all over Sweden. At the site of focus, automation and robotic solutions are designed and implemented.

In the next chapter, more information about HRC is given for the reader not yet familiar with the topic. The paper then continues by describing the set-up for the interview study in chapter 3 and 4. The

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results from the interviews are presented and analyzed in chapter 5. Chapter 6, finally, summarized the conclusions from the study.

2. Background

Research has been done in the area of HRC for many years and involves multiple disciplines such as interaction, safety, path-planning and task allocation to mention but a few. This chapter gives the basic knowledge of HRC necessary to understand the paper, and also describes examples of research studies in which HRC workstations have been implemented.

In HRC a human and a robot share workspace to complete a task, and the idea is to combine the benefit humans and robots into one workstation. Since traditional industrial robots pose a danger to a human when they share the same workspace, industrial robot manufacturers have started to produce collaborative robots to overcome this safety issue. Collaborative robots are robots that can be used in collaborative operations as defined in the technical specification ISO/TS 15066 [4], created by the International Organization for Standardization. Collaborative robots are generally lightweight industrial robots that include force limitations on all joints to make them suitable for HRC. In the literature, there are plenty of studies on HRC and some of the most interesting of these are presented in the following of this chapter.

Sadrfaridpour and Wang [1] presents a framework for human-robot interaction and showcase this framework in a workstation where a human and a robot collaborates. The task that the human and robot executes is to assemble three parts. The human fetches one part and places it in the workspace, the robot then fetches two other parts and places them onto the first part, and finally the human screws the parts together.

Hietanen et al. [5] presents another study in which augmented reality-based interaction is used for collaborating with a robot. The authors propose an interactive user interface for displaying digital information that is projected onto the real world. A workstation is implemented in which part of an engine is to be assembled, adopted from a real-world case. The task consists of five sub-tasks, of which three are manual, one is handled by the robot and one requires the collaboration of both human and robot. In the collaborative sub-task the robot brings a component and activates hand-guidance, which allows the human to guide the robot by hand to position the component.

Peternel et al. [6] presents and demonstrates a multi-modal robot teaching framework which is used to train a robot to physically perform cross-cut sawing motions with a companion human. Their work is an interesting example of when a human and a robot physically interacts to execute a task. In the task, the human and the robot are on opposite sides of the saw only exerting force in a dragging motion. While the robot is dragging the saw, the human mainly follows, and while the human is dragging the saw, the robot mainly follows.

De Gea Fernández et al. [7] presents a multimodal whole-body tracking system used for gesture recognition, intention recognition and collision avoidance. These technologies are implemented on a HRC workstation combining two collaborative robot arms where. In the task, adopted from a real-world case, the human signals the robotic system with gestures to either start or pause the process, or activating a collaboration mode. When the robot cell starts, the two robots assembles the parts while ensuring the safety for the operator by tracking the human and actively avoiding collision. If an inspection is needed, the operator activates the collaborative mode in which the robot picks up the last assembled product and positions it in a comfortable position for the operator to inspect it.

The summarized papers are some examples of studies that show the great potential of HRC in different application areas, and that the technological advancement in robotic platforms have made it possible to implement HRC within the manufacturing industry [2,8]. So far, the identified tasks within HRC are, however, mainly based on theoretical reasoning and/or research experiments, and as previously discussed more investigation is needed to further identify tasks that will be beneficial for HRC.

3. Interview subjects

When it comes to relevant interview subjects for the study there are two types of persons that are of interest: persons that are working with assembly tasks that can potentially be made collaborative, and persons that are working with the planning and/or construction of HRC cells. As previously mentioned, the study is focused on assembly tasks specifically. When identifying interview subjects, three categories of professions were identified:

Automation engineer: Persons with this profession can provide knowledge of the automation process, what can and cannot be constructed, and the capabilities of robots including collaborative robots. In the study, automation engineers with knowledge of automation and development of collaborative solutions were sought after.

Production engineer: Persons with this profession have an overall knowledge and responsibility for the production line. They can therefore provide insight into the production and technical aspects of assembly and what can be improved with the help of an assistant, such as a collaborative robot. Production engineers know the process, the history and development over time in the factory, which gives them a different perspective to that of the automation engineer.

Operators working with assembly: Persons with this profession are relevant because their daily work consists of assembly and they are therefore experts on the process as well as its shortcomings and possibilities. They have hands-on experience of the process beyond that of automation and production engineers and should be able to provide good insight into the current process and its opportunities for improvement. Since they work with assembly daily, they can also provide information on what parts of the assembly process that feel inefficient, stressful, or present ergonomic issues.

In total there were ten participants: four automation engineers, three production engineers and three operators. These participants are further on referred to as A1-A4 for the automation engineers, P1-P3 for the production engineers and O1-O3 for the operators.

4. Interview structure

The interview study was conducted according to the procedure in Figure 1. The study used a semi-structured interview approach, with core questions focused on identifying tasks suitable for HRC. A semi-structured interview approach was selected because it gives the participant more freedom to discuss the topic as they want, but still restricts them to the main theme if they stray too far [9]. The questions were open-ended to avoid guiding the thought processes of the participants. The questions were also adapted to the occupational role of the participant.

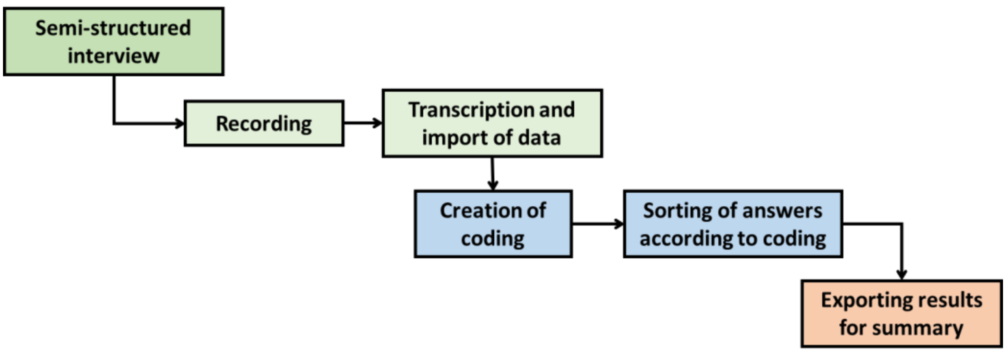

Figure 1. The process of collecting and analysing data in the interview study to extract knowledge of tasks suitable for HRC.

It is well known that the language used during an interview is important, and the interviewer must be able to adapt the language to the interview subject without mimicking or imitating people in any way [10]. The interviewer should thus be able to adapt in such a way that the question and the message become clear without making the situation unnatural. Having this in mind, the interview questions were adapted depending on the occupational role (see section 3) of the interview subject.

4.1. Interview process

All interviews started with an introduction presenting the interviewers, the purpose of the interview, obtaining permission to record, and assuring confidentiality. After getting a signature from the participant, the interview was recorded using a smartphone for the purpose of later transcribing and analyzing the interviews, see figure 1. Then the semi-structured interview started following an interview form which was structured with a set of questions to simplify the process for the interviewer. As the last part of the interview the interview subjects were asked if they had any comments, questions or anything else to add.

Three interview forms were created for this study based on the identified professions in chapter 3, these were used for the interviewer to structure the questions. Each form consisted of a set of phases and each phase had a set of questions with alternative follow-up questions depending on the answers. All forms consisted of the following four phases, with the exception that phase 2 was not used for automation engineers:

Introduction: In the introduction phase, the interview subjects were asked questions with simple answers. This was to warm them up and make them more comfortable in answering the more complex questions that were following [9,11]. The questions used in this phase were the following: "What is your occupation?", "How long have you worked in your current occupation?", "How long have you worked in this company?" and "What was your previous occupation?".

Current status: In this phase, questions were asked about existing problems within the assembly manufacturing line. As the automation engineers were not connected to a specific line or station, this phase was excluded for them. The questions in this phase were used to get an understanding of the interview subject's view of the current situation. The answers were expected to pinpoint specific tasks that are perceived as time consuming, requiring high precision, working with small or heavy objects, working with parts that are difficult to handle parts, ergonomically stressful tasks, or other similar complexities. The questions in this phase are also asked to provide an image of the interview subject's work and to prepare the interview subject to think about tasks that may be relevant to the core question.

Core questions: This was the main phase of the interview, where the purpose was to gain knowledge about what tasks that are suitable for HRC. The core question needed to be carefully formulated for the production engineers and operators since it could not be expected that these were familiar with the possibilities of collaborative robot and HRC. Therefore, the question used for these two categories were formulated as “What could a colleague or an extra person assist you with to facilitate or simplify your task?”.

The questions for the automation engineers directly asked about identifying possible HRC tasks, as this profession were known to have prior knowledge about HRC. They were first asked whether they had previously practically worked with implementing HRC or collaborative robots. If they had, they were asked for more information about that implementation, otherwise they were asked in which tasks in assembly manufacturing they could see possibilities using HRC.

Future analysis: In this phase, questions were asked on how the interview subjects thought that the future would look like. For production engineers and operators, questions were asked about their perception of HRC. If they had no idea what HRC could look like, the interviewers gave a brief explanation. For automation engineers, questions were asked on how they would want to work with collaborative robots and HRC, how it could be tested virtually, and how the robot needs to be further developed to become a more common solution in industry.

4.2. Analysis of interview

After the interviews had been conducted all recordings were transcribed, which simplifies the process to search through and analyze the data [9]. The transcribed text was imported into Dedoose, an online app used for analyzing qualitative and mixed methods research with text, photos, and audio. Codes were created to categorize the answers of each interview subject. The information extracted from the interviews were then carefully analyzed.

From the transcribed material, root codes were created to categorize the answers into “experience”, “tasks” and “improvements”. Sub codes were then created to further divide the code “tasks” into the type of problem that is correlated with the described task. The reason for this code creation is to identify the type of problem within tasks that HRC can be used to alleviate.

5. Results

Based on the results from the analysis, six main categories of tasks were identified where support for the operator would be suitable. These categories are listed in table 1 in alphabetical order. The table shows the opinions of the interview subjects listed in each column, where a checkmark is added for each category of tasks that they mentioned can benefit from HRC.

Table 1. The interview subjects' opinions on potential tasks that can benefit from HRC divided into six categories. A1-A4 are automation engineers, P1-P3 production engineers and O1-O3 operators.

	A1	A2	A3	A4	P1	P2	P3	O1	O2	O3
Difficult to operate	✓				✓		✓			
Logistic inefficient			✓	✓	✓	✓	✓	✓	✓	✓
Non-ergonomic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Product variation			✓					✓		✓
Time consuming		✓	✓		✓				✓	
Uneven quality	✓	✓	✓			✓				

From the results in Table 1, all ten participants discussed non-ergonomic tasks and eight of the participants discussed logistic inefficient tasks. For each of the remaining categories, between three to four participants discussed tasks belonging to respective category.

In the following subsections each of the categories are described in more detail with examples of tasks that the interview subjects discussed.

5.1. Difficult to operate

Automation engineer 1 mentioned that in tasks that requires skill and dexterity with the fingers, a collaborative robot could assist the operator – especially if the task is difficult to perform using another machine or tool. Operator 2 also mentioned the same aspect and gave the entering of small screws as example. Two out of the three production engineers also mentioned tasks where it is difficult to reach as possible tasks when a collaborative robot could be beneficial.

5.2. Logistic inefficient

Most participants mentioned that a collaborative robot could assist in tasks related to logistics around the assembly stations. All operators discussed material preparation and preparation for the next product as an example, and that assistance with surrounding equipment could facilitate such work. Operator 3 mentioned that assistance in loading material and preparing for the next product could reduce downtime and improve productivity. Production engineer 2 mentioned tasks that involve placing details in the station for identification. Production engineer 1 suggested that a collaborative robot could function as a third hand, even in logistics. Automation engineers 3 and 4 talked about a HRC cell that had previously been built and that they used a mobile solution to drive materials to the station. This too could be in the form of an intelligent collaborative robot in the future.

5.3. Non-ergonomic

All participants mentioned that ergonomic relief for the human is a good potential utilization of a collaborative robot, as seen in table 1. One specific task that they discussed was the non-ergonomic entering of screws. Production engineer 1 mentioned that the entering of screws is tiring for the wrists and has affected the employees negatively from an ergonomic perspective. Automation engineer 2 and 3 also mentioned similar entering tasks in their assembly lines. A recurring example of tasks that were mentioned are those that involve repetitive heavy lifting. Automation engineer 4, who had also participated in a project which involved a HRC cell, said that there is a task at their station where the collaborative robot and the human together lift a heavy metal piece. Operator 3 also mentioned that possible tasks for a collaborative robot include when the operator is forced to work at an uncomfortable height.

5.4. Product variation
During the interviews, all automation and production engineers talked about how future production will require increased flexibility. One of the reasons for this was the increased customer demand for product variation in the market. Automation engineer 3 said that the vision for collaborative solutions should be that they are able to cope with the preparation process even if the products change. The robot should be intelligent enough to be updated automatically and be aware of the product type it should adapt to. Automation engineer 3 explained that in future production where more robots and complex systems will be present, it will be difficult for humans to have all the information in their head. Therefore, it would be advantageous if the robot could take more responsibility regarding product changes and preparation for new details. Operator 1 and 3 did not mention any specific tasks but said that smooth assistance in complicated switches between products is something that would facilitate the work.

5.5. Time consuming tasks
Regarding tasks that are time-consuming for the operator, both automation engineer 2 and 3 mentioned parts where many screws must be tightened. Automation engineer 2 thought that such a task could just as easily be done by a robot. Automation engineer 3, who participated in the project with the HRC cell, said that one of the tasks that the collaborative robot performs at their test station is tightening 24 screws. Both operator 2 and production engineer 1 stated that a collaborative robot could contribute to efficiency in the tasks at the stations as it involves several parts during assembly.

5.6. Uneven quality
Regarding quality, automation engineer 2 mentioned a collaborative solution that their company provided which glued dashboards. This was a task previously performed manually, but to reach a uniform product quality, a collaborative robot was implemented. Production engineer 2 also mentioned an existing solution in the company's production. A YUMI robot checks the quality of the product as one of the station's tasks before the product continues in the production line. Neither automation engineer 1 nor automation engineer 3 mentioned any specific task. However, automation engineer 1 mentioned that in general automation is used to achieve better product quality. Automation engineer 3 also mentioned improvement in product quality.

6. Conclusion
This paper presents an in-depth interview study that investigated what industrial actors think are the most value-adding tasks in HRC. Research on HRC has been active for many years but despite this, there are still little knowledge of what tasks are suitable for HRC and the results from this interview study can serve as guideline for other manufacturing companies that consider implementing HRC. Two companies participated where three shop-floor operators, three production engineers and four automation engineers were interviewed. From these interviews, six categories of tasks were identified as being beneficial for the human and robot to carry out together. These categories are tasks that are difficult to operate, logistic inefficient, non-ergonomic or time consuming and tasks that have product variation or uneven quality. Two of the categories of tasks that could benefit from HRC were discussed more than the others, all ten participants discussed about non-ergonomic tasks and eight participants discussed about logistic inefficient tasks. For each of the remainder of categories between three to four participants discussed tasks belonging to respective category.

Acknowledgment
We would like to give a thank you to the participating companies and their personnel that made this study possible. A special thanks goes to Lisa Lexe and Rebecca Nilsson, who prepared and executed this interview study.

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