

The Quest for Appropriate Human-Robot Interaction Strategies in Industrial Contexts

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Abstract. The industrial evolutions require robots to be able to share physical and social space with humans in such a way that interaction and coexistence are positively experienced by human workers. A prerequisite is the possibility for the human and the robot to mutually perceive, interpret and act on each other's actions and intentions. To achieve this, strategies for human-robot interaction are needed that are adapted to operators' needs and characteristics in the industrial contexts. In this paper, we aim to present various taxonomies of levels of automation, human-robot interaction, and human-robot collaboration suggested for the envisioned factories of the future. Based on this foundation, we propose a compass direction for continued research efforts which both zooms in and zooms out on how to develop applicable human-robot interaction strategies that are worker-centric in order to obtain effective, efficient, safe, sustainable, and pleasant human-robot collaboration and coexistence.

Keywords. Interaction strategies, Human-robot interaction, Human-robot collaboration.

1. Introduction

Industrial robots have historically been separated from human workers for safety reasons, but the advent of Industrie 4.0 aims to develop the factories of the future, increasing productivity, quality, effectiveness, and satisfaction [1-3]. The successive industrial evolutions do not only alter the production paradigms but also have significant changes in the relationship between humans and technology [3-4]. The envisioned development in human-robot interaction (HRI) and human-robot collaboration (HRC) is leading to robots being situated in the assembly lines in close proximity to human workers, where they will share workspace and tasks [3-5]. It is acknowledged that robots successfully can assist humans with heavy or repetitive tasks that might cause physical strain in humans if carried out frequently or over too long periods. To complicate the issue, some tasks that are easy for humans are difficult for robots. However, recent technical advancement offers possibilities for a much closer and more complex level of interaction between humans and robots. The interaction between humans and robots is still limited. Still, the shift from separating robots and humans to their envisioned mutual interaction and coexistence on the shop floor of the factories of the future poses several challenges,

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ranging from technological advancements, distribution of work, task-allocations, and safety issues to human-centred aspects [1-2,6-9].

Despite the demonstrated focus on the human-in-the-loop in Industrie 4.0, commonly denoted Operator 4.0 from a human factors/ergonomics perspective [6], we join other researchers in calling for a more worker-centric perspective [7-9]. These voices primarily advocate a more in-depth focus on the experiences of interacting with advanced technology as robots as well as increasing work engagement in the factory [7-8]. It has been emphasised that the factories of the future should be more worker-centric to further optimise production performance, stressing that the workplace primarily should fit workers' needs, and then technology should be developed that supports the work tasks that should be carried out in the particular context [7-11].

A major challenge is identifying and formulating effective, efficient, safe, sustainable, and pleasant interaction and coexistence that should be positively experienced by humans that are situated in the same physical and social context as robots, in which a key enabler is the ability to mutually recognise and respond to the actions and intentions of each other [10-11]. From the workers' perspective, it should be possible to easily perceive what the robot is about to do, e.g., via social signals and movements, and being able to correctly recognise and know how to act upon its actions, which enables the worker to experience predictability for perceived safety and control [10-11]. To achieve this, appropriate taxonomies and applicable strategies for human-robot interaction are needed, which can be adapted to the tasks at hand, operators' needs, preferences, and characteristics in the particular industrial context. Otherwise, the collaboration between workers and robots runs the risk of being inefficient, unsafe, and practically inoperable.

The purpose of this paper is to propose a compass direction for continued research efforts to develop applicable human-robot interaction strategies that are worker-centric in order to obtain effective, efficient, safe, sustainable, and pleasant human-robot collaboration and coexistence. In section two, the move from levels of automation and collaboration to human-machine relationships is described. Next, related work on HRI strategies is presented. The paper ends with concluding remarks and outlining identified challenges and future work.

2. From levels of automation and levels of collaboration to human-machine relationships

Common ways to characterise levels of automation in human-machine/robot interaction are described in work by Frohm et al. [12] and Sheridan and Verplank [13]. They examined how the task responsibility is distributed through different levels of human-machine interaction, illustrating several levels that range from complete human control of an operation to fully autonomous operation in all conditions. As pointed out by Kolbeinsson et al. [3-4], an interesting aspect of these levels of automation, independent of the number of levels, is that they are depicted as a single dimension, i.e. how much of the work is performed by each of the human and the automation in the activity, thus the collaborative dimension is totally missing. However, Shi et al. [14] proposed three levels of collaboration (low, medium, and high) considering the sharing of workspace and collaboration, although the so-called collaboration did not include active collaboration in a shared space and tasks simultaneously. Therefore, Kolbeinsson et al. [3-4] stressed that the above authors [12-14] did not explicitly describe how or what kinds of interaction

or collaboration should be achieved, lacking specifications of task-allocation as well as not addressing whether the tasks or space are shared or separate.

Michalos et al. [5] examined various aspects of human-robot collaboration, focusing on various kinds of interaction in their proposed taxonomy. The taxonomy involves classifying a shared cooperative activity into whether i) the task is shared or separately conducted by the human and the robot, whether ii) the space in which the task is performed is shared by the human and the robot, or whether iii) they each have their own (separate) or shared space. Michalos et al. [5] highlighted that in many cases of human-robot collaboration, the robot's workspace is shared with the human which adds physical proximity. A detail pointed out by Kolbeinsson et al. [3-4] is that [5] classified a shared common task in a shared space in which either the robot or the human is active at the same time. This means that although the task and the space are shared, the task does not require that *both simultaneously are active*. Thus, they did not perform any joint actions as described in the human social interaction and cognition literature [15-16]. Michalos et al. [5] suggested that the taxonomy could be further developed, depending on the levels of interaction between humans and robots.

Another model of the human-machine relationship is the 5C model, referring to Coexistence, Cooperation, Collaboration, Compassion, and Coevolution, which belong to certain industrial evolutions [9, 17]. Pizon and Gola [9] described that 'Coexistence' refers to when man and machine have monitored coexistence in the same environment and share the same space, but without the need for mutual contact or coordination. 'Cooperation' refers to a group of agents in a collaborative situation in which there is a 'master-servant relationship'. 'Collaboration' refers to human-robot interaction, in which the human worker and the robot are situated at the level of master-collaborator since the two work together to fulfil a common goal through various means of interactive dialogue (e.g., gestures, speech, haptic contact). These cobots will be designed to be aware of human presence, by noticing, understanding, and learning from the humans, but also perceiving their goals and expectations. 'Compassion' and 'Coevolution' envision a kind of "empathic machines" that has the capability to sense human emotions, needs, and preferences, and therefore able to offer situational assistance beyond cooperation. It is foreseen that humans eagerly will care for these empathic machines in a reciprocal manner, manifesting human-machine empathy. This bond will develop into more intimate human-machine interactions that eventually enable the growth of human and machine capabilities, resulting in a forthcoming human-machine co-evolution [9]. Central to this relationship is how workers feel in this environment, how decisions are made, who makes them, and how trust is created and experienced [9].

McGirr et al. [18] proposed a taxonomy of interaction levels that provides a classification of increasing levels of interaction. The terms are 'Coexistence', 'Sequential', 'Simultaneous' and 'Supportive' which were chosen to decrease the ambiguity of interpretation of the four degrees of interaction that involve an operator and a robot situated in a *shared* workspace [18]. Coexistence refers to the shared workspace in which the operator and robot work on separate tasks and *workpieces* used. The significant addition of this taxonomy is the inclusion of workpieces that are not explicitly mentioned in other taxonomies or levels of collaboration. It should be acknowledged, however, that the more advanced the human-machine relationship/interaction level will develop, the higher the demands on the mutual action and interaction recognition capabilities in both humans and robots will be. There are neither detailed descriptions nor explanations of *how* this will be achieved by the above examples (for a thorough

description of various levels of social interaction and cognition in human-human interaction, see [15-16]).

Arents et al. [19] conducted a literature review on recent trends in HRC, and they identified several HRC methods for what they denoted as more intuitive collaboration. Some suggestions were that the human needs to be aware of the robot's movements and actions, but the robot also needs to be aware of human intentions. They [19] pointed out that some articles addressed this aspect by detecting and recognising the human body, gestures and through synthesising and recognising speech for more natural communication. They did not, however, provide any specific kind of interaction strategies about how these should be designed or on task-allocation.

3. Related empirical work on human-robot interaction strategies

Schmidbauer et al. [20] studied whether industrial workers preferred static or adaptive task allocation as well as what tasks they did prefer to assign to the cobots in a practical assembly context. They used a cobot demonstrator to set up a realistic industrial assembly scenario and recruited 25 experienced workers. Their results show that the workers preferred the flexible adaptive task sharing in a predetermined task allocation and stated increased satisfaction with this allocation. Workers were more likely to provide the cobot with manual tasks than cognitive tasks. They concluded that the workers do not delegate and trust all tasks to the cobot, but prefer to finish cognitive tasks by themselves to be in control.

Tausch et al. [21] examined how worker influence in task allocation improves autonomy. Usually, this kind of research focuses on efficiency, but procedural, motivational and cognitive perspectives are suggested to empower human-centred HRI [21]. There were 87 subjects participating in a contrived study where they performed manual assembly in collaboration with a robot. Three conditions that were used where i) a support system selected the allocation, ii) they could alter the system's allocation, and iii) they selected the allocation. The results show higher values when the participants allocated tasks themselves and satisfaction seems lower with no worker influence. It was concluded that workers should be provided with influence over task allocation for a successful HRI [21].

Schulz et al. [22] studied how humans want to interact with a collaborative robot, by investigating preferred interaction styles in HRC that varied over tasks with different types of actions in several experiments. They pointed out that *interaction styles*, i.e., the ways a robot can interact vary with regard to either autonomous action or command-driven action, also can affect the efficiency of interactions and human perceptions about the robot. They portrayed three main styles for these interactions: 'autonomous', 'human-led', or 'robot-led' interactions. These terms indicated who initiates the interaction and drives the human-robot interaction to task completion. In addition, they described seven *interaction strategies* (autonomous, proactive, reactive, human-requested, human-commands, robot-commands, and information), which they tested in a series of experiments that were combined with autonomous, human-led, and robot-led interaction styles [22]. They categorised several forms of collaboration along two dimensions: On the one hand, they distinguished between *independent actions* and *joint interaction*. On the other hand, they distinguished between *sequences* where the order was either *crucial* or *not*. This was assessed in a series of simple table-top scenarios in which a human collaborated with a robot to assemble a given design with blocks. They

aimed to investigate and analyse tasks with different interaction styles that the robot could use to choose its actions, together with different interaction strategies to identify the specific situations, in which the human participants preferred different interaction styles [22]. The results from a series of experiments show that humans and robots acting autonomously were perceived as more efficient interactions. However, in joint action situations, human-led interactions were the preferred style whereas in high cognitive load situations, robot-led interactions were preferred. They [22] pointed out that joint actions are gained from timely information communicated between humans and the robot. Moreover, it was revealed that actions that demanded a higher cognitive load benefitted from the robot's additional information by communicating its plan about what the human should perform. The authors [22] concluded that different interaction styles are preferred for different tasks with respect to independent versus joint action, and whether the order of actions was fixed or not. Hence, it is therefore important to consider the type of task for designing robot interactions. It was suggested that future work should be conducted with more advanced tasks in more complex situations.

4. Concluding remarks, identified challenges and future work

In this paper, we revealed that, although many taxonomies and levels of collaboration exist in human-robot interaction, knowledge and insights on successful interaction strategies for achieving mutual actions and intention recognition between humans and robots in manufacturing contexts currently is understudied. We suggest that future work in HRI and HRC should, to a larger extent than currently is being done, take more inspiration from socio-cognitive theories of human interaction and collaboration as researchers are doing in the social robotics field [10, 23]. Besides disentangling the scattered use of inconsistent terminology, a deeper theoretical basis may provide faster progress and more efficient outcomes for identifying and implementing appropriate human-robot interaction strategies in industrial contexts, which should be beneficial in many aspects.

Therefore, we suggest that future work should, on the one hand, zoom in on the analytically distinct levels of work activities phenomena [10-11]. On the other hand, we also need to zoom out, going beyond the current human-robot dyad [24], since the envisioned factories of the future will consist of mobile robots that interact with different operators or even other robots that are distributed over time and space on the shop floors.

Acknowledgements

This research was financially supported by AIHURO [2022-03012] which is sponsored by Vinnova, Sweden.

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