Empowering Workers in a Mixed Skills Concept for Collaborative Robot Systems

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***Abstract*—One aspect of digital transformation in manufacturing is the trend toward mass customization, which requires a more flexible production paradigm. Human-robot collaboration and knowledge-based engineering are approaches that meet these requirements. In our work, we combine them in our mixed skills concept that incorporates the strengths of human workers and robots. We assume that while the workplaces of many workers may change, they will continue to play a vital role due to their experience and flexibility. They can perform various types of tasks that are still beyond the capabilities of robots. Yet, their responsibilities may shift towards decision makers and problem solvers for robots. Our approach to facilitate such collaboration is to apply insights from social science regarding empowerment in the work context to determine design goals and potential solutions for collaborative robot systems. The technical implementation is based on semantic descriptions of relevant aspects of automation using OWL ontologies and intuitive user interfaces.**

I. Introduction

For a long time, automation was – and usually still is – thought of as a replacement for human workers. However, complete automation may not be feasible or even desirable in the foreseeable future, e. g., in SMEs or mass customization applications due to the unique physical and mental skills of human workers. The ongoing digital transformation in automation may lead to and require a closer and thus more integrated collaboration between humans and robot systems. The associated changes to workplaces may require new design considerations, e. g., so that the unique advantages of human workers are not lost. Additionally, the role of humans may shift to some extent, e. g., from manual workers and machine operators to decision makers and flexible problem solvers [6].

This gradual process imposes new challenges. Due to the increasing degree of automation, the tasks of human workers will likely become more fragmented and thus more complex. This can be compensated by algorithmic support in the assignment of tasks to human and robotic actors. However, this can only partially tackle the complexity. Complementary to this are the adaptivity and flexibility of humans, who can effortlessly react to unforeseen situations. Yet, this requires that human workers are motivated and feel empowered in their work.

In brief, *empowerment* aims at (re)establishing self-determination over the circumstances of one's own every day life [7]. In our approach, we take into account insights from social science regarding empowerment in the work context. We would like to design a collaborative robot system accordingly by providing human workers with more autonomy and decision-making opportunities.

As a first step, we introduce the concept of *mixed skills*, which at its basic level is a common semantic model for the skills of humans and robots that can be interpreted automatically, e. g., to control robots or instruct humans. There may be tasks (productions steps) that can be performed by only humans, only robots, or both, while for some tasks they could or must work together. Furthermore, a closer *human-robot collaboration* (HRC) and more frequent context switches regarding the assignment of tasks to a human or robot may emphasize their different and often complementary strengths.

The main contributions of this paper are our mixed skills concept and the incorporation of empowerment factors (Section III). Furthermore, we describe how this can be realized via ontology-based semantic models (Section IV). The last contribution is suggestions for an intuitive user interface that brings the concept to the worker (Section V). Not all concepts and suggestions have been integrated yet, but they serve as a base for new technical demonstrators.

II. Related Work

There is work on empowerment in manufacturing without robots and empowerment outside manufacturing with robots. Dubey and Gunasekaran [3] present an agile manufacturing framework based on a literature review that includes the empowerment of the workforce in general. Although it mentions robot worker platforms, it does not relate them to empowerment aspects. Charalambous et al. [2] recommend creating operator empowerment plans for implementing industrial HRC, which indicate the level of operator control over the system, as they help operators understand their system and empowering them to make decisions is preferable for complex automated systems. Grüneberg [5] proposes a framework for the high-level design of social robots and applies it to a medical physical rehabilitation and a childcare scenario.

In [13], a knowledge-based engineering approach was presented that uses skill models for the generation and execution of robot programs in small lot production. In [12], semantic process models were combined with intuitive user interfaces to make robot programming easier without extensive training. Both approaches do not specifically consider empowerment aspects. Another intuitive user interface with a focus on task-level robot programming was presented and empirically validated in [15] and [16].

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Our proposed concept considers both knowledge-based robot systems and the empowerment of workers in manufacturing, in order to benefit workers and companies alike.

III. Designing Empowerment

To address the question of how to design a collaborative robot system that empowers human workers, we use participatory and qualitative research methods, consider possible ways of how human workers can be embedded in the working context, and conclude how working practices could change due to the introduction of a collaborative robot system.

There are three dimensions to empowerment that we will focus on: content, time and informal workplace learning.

1) Content: In order to develop a collaborative robot system that takes the empowerment of workers into consideration, we have to identify what kind of tasks can be done (a) only by a human worker, (b) only by a robot, (c) either by a human worker or a robot, (d) only if a human worker and a robot work together simultaneously, (e) only if (at least) two human workers work together simultaneously. Our aim is to *enrich* human work, give the workers more decision-making opportunities, and expand their *scope of action*. Therefore, the collaborative robot system can, e. g., offer them to decide which tasks the robot or they themselves have to complete next. This way workers can experience more coordination work and also a sense of *a complete action*. In order to achieve this goal, user interfaces must be intuitive and provide comprehensible information about the relevant context and feedback about the previous, current, and next task(s) as well as the goal (see Section V). Additionally, alternatives, explanations, and background knowledge should be displayed in a comprehensible manner to facilitate the ability to act and make decisions. Finally, even though monotonous tasks are widely considered harmful, they might be of great value to workers if they are wisely chosen by themselves once in a while and provide some sort of relieving flow.

2) Time: We also have to consider the time dimension – e. g. duration, speed and schedule: A worker might be able to accomplish a certain task once or for a period of time, but not permanently. Also, a job enlargement without any benefits for the human worker must be avoided. Workers should also be empowered to decide the speed and duration of the HRC (beginning, end and breaks) – without neglecting the completion of the predefined work packages.

3) Informal workplace learning: From the very beginning, we take various interaction scenarios into account and how informal learning can be supported while working and interacting with a collaborative robot. Of course, we are aware that learning processes are carried out by each human individually and that intrinsic motivation is of great importance. Also, we are aware that technology might be used in everyday work differently than one might expect beforehand [17]. Still, we think that it is beneficial for both the workers and the company to design a collaborative robot system that gives humans the opportunity to learn new skills, acquire more knowledge, and gain experience while working. Accordingly, we promote the idea of *designing* informal workplace learning – in addition to formal learning opportunities such as workshops or advanced training courses [4]. Therefore, we have to think about a HRC that provides a beneficial learning environment in itself: e. g. opportunities to make mistakes, to retrieve, to elaborate, to reflect (e. g. [1]). Accordingly, the user interface must meet this requirement, e. g., by being explainable. To preserve experience and knowledge, it might also be important to allow and encourage workers to perform tasks occasionally that can be easily performed by a robot.

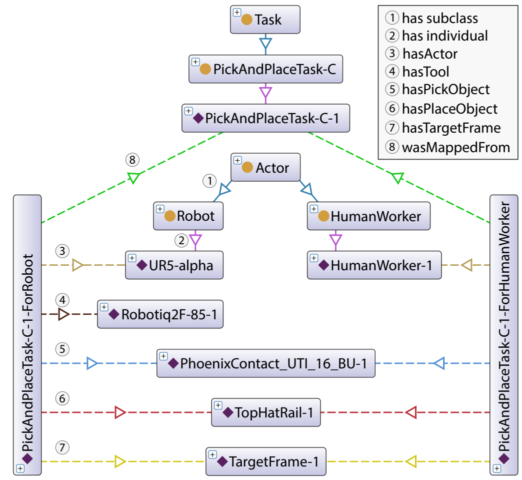

Fig. 1. Visualization of an example of a semantic task description. Tasks can be mapped to human or robotic actors while using the same high-level parameters. Boxes with yellow circles represent classes and boxes with purple rhombi represent instances of these classes.

Finally, it is reasonable to assume that a worker's job profile might change due to flexibility requirements, new responsibilities, and different tasks. Some workers might even be overwhelmed by more autonomy and decision-making opportunities, while at the same time, predefined work packages still have to be completed on time. Therefore, it is important to take these concerns seriously by designing a realistic and adjustable workload and react with support and qualification.

IV. Formalization and Envisioned Concept

Our approach to facilitating these empowerment factors and enabling HRC in a mixed skills context is based on formal descriptions of skills. We intend to implement our concept in a collaborative robot system by extending a knowledge-based digital engineering approach [13]. In this approach, we define and query ontologies using technologies from the Semantic Web stack, e. g., the *Resource Description Framework* (RDF), the *Web Ontology Language* (OWL), and the *SPARQL Protocol and RDF Query Language*. Such ontologies can be interpreted by preexisting and custom reasoning components to assess their logical consistency and to derive implicit knowledge from explicitly modeled facts.

To provide the necessary context for mixed skills, our preexisting ontologies representing relevant aspects of automation tasks (e. g. products, manufacturing processes and resources) can be used and adapted. In order to assign tasks to human or robotic actors and have them perform them, the skill set of each actor needs to be formally represented. For a robot, this requires a fine-grained description of its capabilities, where the skills are callable functions with exact restrictions on their scopes. A human's capabilities on the other hand can be described on a more abstract level, e. g., with regard to ergonomic best practices or specific competencies such as those found in the semantic ESCO classification[1].

A manufacturing process is represented by a semantic description that contains a sequence of tasks, which can be linked with abstract parameters such as interaction objects or relevant geometric constraints, e. g., for defining grasp or assembly poses. They can refer to particular parts of an object, as our semantic object models contain exact geometric descriptions based on a *boundary representation* (BREP) in an ontological representation [11]. Other entities from heterogeneous data sources along the value chain of a manufacturing company could be similarly linked to provide humans and robots with relevant context information in a seamless digital system. By using the same formal representation for all the different types of entities, a highly interwoven knowledge graph is spanned.

This semantic knowledge can be used to assign tasks by automatically matching the requirements of individual tasks to the currently available skills [18]. As part of this procedure, processes can be automatically adjusted for different actors. For instance, based on a high-level description of a pick & place task, robots may be controlled via automatically derived subtasks that correspond to low-level arm and gripper commands, while for a human explicit tool-changing tasks could be skipped. While the resulting specific task descriptions have different actors, they share many other parameters (see Fig. 1). Tasks assigned to a robot system can then be performed by commanding the robot or another device component by executing their skills on a hardware and software level. Tasks assigned to a human provide the necessary information to parameterize generic communication strategies, in order to visualize, verbalize, or potentially even demonstrate a task.

V. Human-Machine Interface

HRC requires interfaces between the two, e. g., to exchange information. Such interfaces are typically graphical, but other modalities can be used depending on user preferences, e. g., speech or gestures. Output modalities such as augmented reality can also be advantageous.

We design a user interface that meets the requirements for empowering the human worker. It considers the introduced empowerment dimensions: content, time and informal workplace learning (see Section III). In the following, we give examples for how this is realized. The foundation of these aspects is usability [9], therefore the interface is developed in accordance to the ergonomics of interaction principles [8] and visual presentation of information [10].

As mentioned, workers should be able to self-organize their tasks. The interface allows to intuitively distribute tasks

[1]https://ec.europa.eu/esco/portal

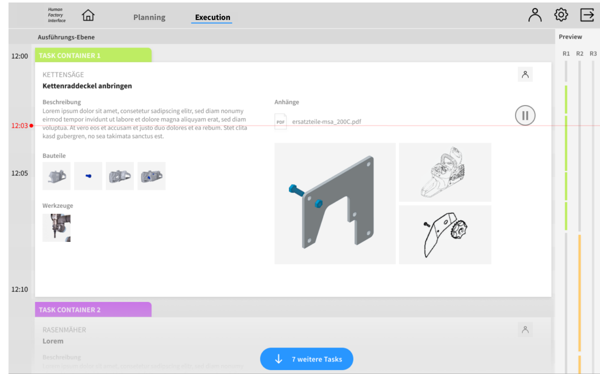

Fig. 2. HMI concept visualizing task descriptions and extra information about the larger process context such as the workload of collaborative robots.

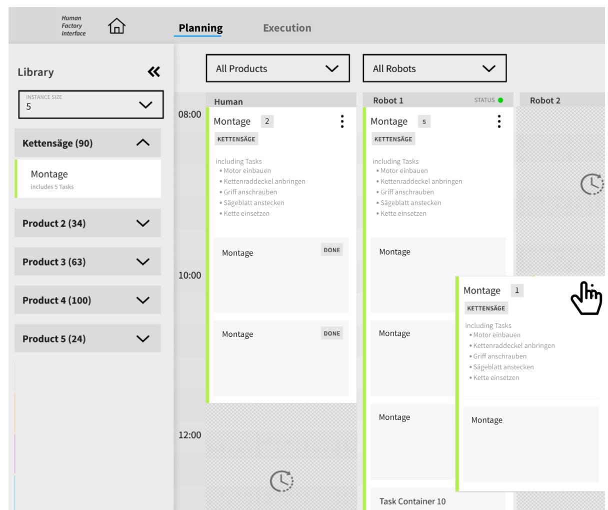

Fig. 3. HMI concept showing the assignment of tasks to a human worker and robots with extra information about their idle times.

between a human and robots, based on their underlying requirements and capabilities. This is supported by information about the effects on different metrics, e. g., production time. Additionally, the distribution of tasks can be based on the degree of capacity utilization of the system and the dependencies of the robot on the human worker.

The interface supports the assignment of tasks by providing the user with suggestions. This is based on several metrics, both of technical/ecological nature (e. g. speed, error rate) and empowerment nature (e. g. work content). Some criteria have been mentioned in Section III; they are operationalized using the concepts described in Section IV.

Another empowerment aspect is *explainability*, i. e., the information or feedback given to the operator. For this, contextual information about tasks, goals, and the production environment is displayed to the user. This includes the description of tasks and the idle times of the human worker and robots.

Figure 2 and 3 illustrate potential HMI designs that were created based on the aforementioned principles. They will be embedded in a *Human Factory Interface* (HFI) that allows to operate multiple (robotic) work stations of a factory [14].

VI. Conclusion and Outlook

Digital transformation and automation will likely change manufacturing workplaces and require new considerations when designing collaborative robot systems. We introduced our mixed skills and empowerment concepts, as well as associated ontological formalizations and intuitive user interface designs. They aim at preserving worker autonomy, facilitating informal workplace learning, and making the system easier to use. We think that empowering human workers eventually enables companies to offer a better workplace, counteract skilled labor shortage, and expand organizational knowledge.

We plan to extend these concepts and their early implementations, and incorporate them into our robot systems to set up technical demonstrators. Additionally, we intend to investigate this topic empirically by interviewing and observing employees in various roles at their workplaces.

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