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Human-robot cooperation in future production systems: Analysis of requirements for designing an ergonomic work system

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Abstract

Both humans and robots have crucial advantages regarding industrial assembly processes. While robots ace at repetitive and monotonous assembly steps, humansare able to adapt flexibly to new situations and upcoming problems. Combining these advantages by means of direct human-robot cooperation seems to be interesting for producing companies but has not been realized yet. While the corresponding technologies are already available, appropriate safety standards to ensure occupational safety are missing and represent one of the main barriers for introducing direct human-robot cooperation. This paper describes the requirements for a workplace, where humans and robots jointly perform an assembly process without separation between their workspaces. The requirements are identified in line with an ergonomic workplace for different aged working persons, whereas the robot assists the human with the assembly process.The analysis considers technical, human-related, and normative requirements. Afterwards, an early implementation of the concept is presented based on a cognitively automated assembly system using a lightweight robot.

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*Keywords:*Human-robot cooperation; Ergonomic work conditions; Occupational safety; Cognitive automation

1. Introduction

The assembly process of today's manufacturing companies can generally be decomposed into two categories of assembly steps. First, there are many assembly steps that can be performed autonomously in an effective and efficient manner using standardized industrial robots or handling devices. The corresponding automation

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technologies have been developed rapidly in the last decades and can easily be used to build up an autonomous assembly line for simple products. However, the second category includes those tasks that cannot be fully automated mostly due tospecial sensorimotor skills that are necessary to succeed in these task[1,2]. Wiring harnesses or seals are, for example, limp components that cannot be controlled properly by today's automation techniques. Besides that, small lot sizes could also make investments in special automation and control technique uneconomically[3].

Therefore, the human operator will still be involved for a long time in the assembly process of many products, whether for performing certain assembly tasks or for supervising the automated assembly process. Combining the advantages of both, the human operator and robotic assembly systems, increases the performance of the overall system most efficiently [2,4]. If products would be assembled cooperatively by the human and the robot, the robot could take over monotonous and strenuous tasks, in order to assure a constant quality and to improve the ergonomic work conditions. In addition, heavy weights or hazardous parts can be handled by the robotto relieve the human. As a consequence, the human is able to concentrate on the tasks that require his/her special skills, such as sensorimotor skills and creative problem solving.

However, currentEuropean laws and norms do not allow for a direct cooperation of the currently available industrial robots and the human. DIN EN ISO 10218-1[5], for example, prescribes either a strict separation of the workspace of human and robot or at least an observed stop of the robot in case the human enters the collaboration space.Due to thehigh forces evoked by traditional robots, mechanical guards, such as safety fences, or electro-optical sensors ensure the occupational safety of the human as presented for various workplaces in [1].However, such a strict separation of the workspaces prevents direct human-robot cooperation and, in particular, the simultaneous interaction of human and robot within the same space. Supporting actions such as adjusting the position of the work piece dynamicallyare not realizable while the operator processes the object at the same time.

In order to solve this dilemma, on the one hand new norms and laws are necessary. The draft standard ISO/TS 15066 [6]promises to fill this gap by specifying among others maximal action forces for collaborative robots. On the other hand, new technologies and control paradigms could help reducing the risk for the human to an acceptable level. Some of them are retrofittablefor existing robots such as cameras, that are able to recognize the position of the human,or capacitive shells for the robot (e.g. [7], [8]), which predict and avoid collisions with the human. These technologies would circumvent the large barrier for companies of buying new robots.Opposed to standard industrial robots, lightweight robotsrepresenta new generation of robots,which are restricted in force but are nevertheless able to carry large weights compared to their own weight. In addition, some of them are equipped with lots of sensors in order to measure forces raised by objects or the human in case of contact. Assuming that the conditions for human-robot cooperation were defined by new standards such lightweight robots would be co-workerfor the human operator.

In this paper, the requirements resulting from the above challenges are identified for workplaces, where the human and robot can work together at the same time without any separation of the workspaces.The requirements are distinguished into functional, human-related and normative requirements, which are described in the following section. In addition, social and ethic aspects have to be considered including the degree of substitution of the human by the robot that is tolerated by humans and the degree of acceptance for the technical co-worker. These aspects will be examined separately, for instance, in terms of user studies. Based on the requirements described in this paper, an approach for a flexible assembly workplace for human-robot cooperation is presented.

2. Requirements for a collaborative workspace for human and robot

2.1. Method

The presented requirements analysis aims at designing a collaborative workspace, where both human and robot perform assembly or manufacturing tasks in a joint working area. We aim at abolishing the strict separation of the workspaces and the temporal alternation of the work process between human and robot.Human and robot should instead work cooperatively on the same product at the same time. In case of consecutive actions, components need to be handed over from the robot to the human and vice versa. Thereby, we likewise aim at direct interaction, i.e. one subject takes over the object directly from the other.However, work tasks related with dirt and dust are excluded as well as those requiring special clean conditions. The workplace is to be aligned for skilled manual workers of all