This is the accepted version of the conference paper published at Springer. The final publication is available at Springer via https://doi.org/10.1007/978-3-031-61688-4_28.

On the Interaction between Construction Vehicles and Humans in Close Cooperation

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Abstract. In the spirit of the Czech translation of the word "robota" as the forced labor or worker, this paper discusses the interaction with increasingly automated robotic workforce working in cooperation with humans for industrial applications, for example, the construction industry. Nowadays, workers in the construction industry control their vehicles as operators. As their vehicles get increasingly automated, development leads to new types of interactions, where humans work together with robot-like machinery. We propose that such development will fundamentally change the type of interaction and decision-support systems needed to collaborate with increasingly automated construction vehicles.

Keywords: robotics vehicles · construction vehicles · collaborative interaction · human-machine teaming.

1 Introduction

Robotic systems are common in the assembly lines of industrial production plants. Recent advancements are starting to take them out of fenced areas, and into acting safely and collaborative with humans [14,22]. However, robotic systems are less common in other industrial settings, such as construction sites, mining, forestry, or agriculture. Nevertheless, the machines used today are becoming increasingly automated, computer-controlled, and robot-like. An example that illustrates this is the combine harvester used in agriculture, which successfully changed the proportion of farmers in the US workforce from 38% to 3% within a century [4]. These machines have evolved from being only mechanical and directly controlled, to using systems with increasing levels of automation and computerization. Their systems adjust production and movement speed to supply the requested quality and level of harvesting using sensors, cameras, and image analysis [3].

Research prototypes of even more robotic vehicles are presented in both academia and industry, where robotic systems have demonstrated the potential benefits for certain tasks, for example, mass excavation and material loading [1,20], weed control [19], fertilizing or moving [12], wall building [7], mining [11], and material transportation [23]. However, despite the huge benefits of using automated machinery, Pedersen et al. [13] conclude that more complex tasks are nearly impossible to automate due to the required accuracy of the specification of the task. Humans are still more versatile and better at adapting to changing conditions, while machines still must be programmed specifically for each task [6]. Therefore, it is of interest to investigate the interplay between humans and robots fulfilling tasks in collaboration by utilizing each other's strengths.

2 Evolving Interaction

The interaction with manual or semi-automatic systems that we have nowadays is done via input devices, such as joysticks, buttons, pedals, and output devices, such as instruments, displays, and audio cues for specific events [24]. As systems get more automated, operators spend increasingly more time monitoring and ensuring system performance than performing actual operation [16]. The increasingly automated operation performed by the robotic system will likely also require higher coordination between the robotic system and another human. Operators need to know what the machine is doing now, why the machine is doing that, and what the machine will do after that.

One scenario is that the human is traveling with the machine, monitoring and assisting the machine or performing parallel tasks. Here, there are opportunities for information exchange that could convey the robot's understanding of the world and its intentions using, for example, using augmented reality or interactive windscreens [18], as well as other embodied means of communication such as haptics [9] or acoustic communication [10]. Different forms of instruments and display information would also be beneficial when interacting with highly autonomous systems. Displays are useful for showing complex and granular information, as well as allowing input to the system using touch control. In addition, the robotic system and humans can share a common visualization of the work area and the task to be performed, in the same way humans use blueprints and sketches. Display-based systems can also be used to communicate and be constantly informed on the status of the vehicle, such as its position and work plan.

More embodied interaction with humans, including voice, gesture, facial expressions, etc., is more common in personal or professional service robots [21], such as the rich interaction with ASIMO [15] or ERICA [8]. Moreover, Sheridan [17], in his list of status and challenges for human-robot interaction, concludes that the intimate collaboration with humans in manipulation tasks, as well as having mutual models between humans and computers is still a research challenge. Villani et al. [22] also highlight that collaborative robots in the industry are still underused.

It is not uncommon that industrial robotic systems target fully automated systems, which do not require any human intervention. Although this approach could potentially improve productivity, Goodrich et al. [5] note that it is likely that the usefulness and safety of robots in many of these domains would increase if human-robotic interaction considerations are included in their design. Nowadays, a machine operator at a construction site might work together with one or more human workers. They collaborate to accomplish a task using verbal and gestural communication, which is critical to perform the task efficiently. Following are two examples that we derived from our field studies:

2.1 Excavators

The first example is from a construction site, where an excavator and a ground worker are preparing a trench for underground piping (see Figure 1). The excavator does the heavy lifting of moving and distributing gravel material to make a flat base in the trench. The co-worker works in the trench to check the actual height and correct slope, instructs the excavator operator where to pour additional gravel, and makes fine-grained adjustments. The excavator operator must pay attention to the location of the ground worker, to avoid pouring gravel over the ground worker, or hitting the ground worker with the bucket when he steps in to make a measurement. When more gravel is needed, the ground worker makes a waving gesture to indicate that more gravel is needed and points out where to pour the gravel. As long as the waving continues, more gravel is

Fig. 1. The picture taken from the cabin of an excavator, which shows the ground worker giving instructions to the excavator operator about where and how much the gravel should be poured.

poured. There is even communication on increasing or decreasing the amount poured by alternating waving behavior. Upon oral communication between the ground worker and the excavator operator, the operator moves the excavator's boom away from the ground worker to avoid the risk of injury, but also to get the operator's cabin closer to the worker.

2.2 Mobile Cranes

The second example of collaborative work between the construction vehicle and human workers is a mobile crane working at a construction site (see Figure 2). The main task shown in Figure 2 is to lift prefabricated wall panels from a truck to the correct location at the property. In general, how the communication is done in this context follows a similar pattern as in the previous excavator example, where the crane operator and the two ground workers communicating with gestures. Moreover, before lifting the wall panels from the truck, the operator monitors that the straps carrying the wall panels are properly attached to the crane wire. The operator can also see whether the ground workers at the site are ready for the next wall by observing their work. Upon unloading the wall panel, there is also a collaboration between the ground workers and the operator in placing the wall panel. The ground workers advice the operator to make a small movement needed to place the wall element at the exact right location. The ground workers are also actively moving the wall panel by rotating and pushing it to the right place.

3 Discussions

The two examples presented in Sections 2.1 and 2.2 can be used as the scenarios to discuss the interaction between robotic systems and humans. For example, replacing the machine controlled by an operator with a fully robotic system that would aid the human worker in fulfilling the same task. In both examples, it is obvious that gestures are the crucial type of communication. The robotic system needs to detect the gestures, understand the meaning of the gestures, and determine whether such gestures were intended for the robot or someone else at the worksite. The robotic system must also be aware of the operations performed by the human and be able to collaborate with human workers, such as the case of the fine-grained interaction during the placement of wall panels (see Figure 2). In addition, vehicles nowadays also perform tasks that were not specified when they were manufactured [2]. Therefore, to provide full support at the workplace and natural interaction, the system might also need to interpret instructions to do new types of actions.

To allow the operator work closely with the machine, the system must also be reliable and trustworthy. This involves safety and security standards, as well as a well-implemented interaction preventing dangerous situations. For example, the robot stops its movement when humans are in close vicinity or performs more subtle communication, such as slowing movement or changing the engine's

Fig. 2. The picture taken from the cabin of a mobile crane, which shows two ground workers ensuring the prefabricated wall panel is placed correctly.

revolution per minute (RPM), which indicates that the machine is aware of the human nearby and intention of action. Since the context is in the professional setting, one option is to establish new types of interaction different from the ones currently used between human workers and operators. Although this could be a plausible solution, it would also require a lot of training for the involved users.

Moreover, it is also expected that more work would be increasingly performed by robots, for example, by having a robot perform the tasks of the ground worker as well. Such a case would require even more critical decision-making from the robotic system, such as adapting and managing unforeseen problems, occurring obstacles, or adjusting to changing conditions. This also puts requirements on critical interpretation, decision making, and communication by the robotic system. A human co-worker might want the robotic system to do something that might be out of the robot's physical capability or something that might harm the robot or its surroundings. The robotic system must be able to interact with its human counterpart and express why a task cannot be performed. Alternatively, the robotic system could also provide prediction to the human worker, which indicates how the robot will perform the task and what the end result will be.

4 Concluding Remark

There are many potential benefits from robots and humans working in collaboration. In this paper, we have shown two examples of current practices in construction vehicles to derive potential interaction, where robots and humans work together to solve tasks that are critical in terms of maintaining the safety of human workers and the quality of the end result. Making the interaction between robots and human workers natural and smooth is a timely and relevant research problem.

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