Automation and robotics in the context of Industry 4.0: the shift to collaborative robots

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Abstract. This paper describes the role and place of collaborative robotics of industrial automation in the context of rapid industrial development. Collaboration of humans and robots in close proximity in a single working space is a stimulating feature of Industry 4.0. Urgent research issues in the field of industrial robotics include problems of developing safer robots in human-machine interaction systems. Due to the close collaboration between humans and robots, many of the problems of industrial robotics are associated not only with technical issues, but also with social aspects. Optimization and automation of production through the introduction of robotic solutions is widely used. In future it will become the basis of all business processes.

1. Introduction

Experts believe that the "industrial revolution" will change the whole world, not just the principle of production. In this case we are talking about the fourth industrial revolution, or as it is called - Industry 4.0. If you do not go into the controversy of specialists, you can follow the opinion of Klaus Schwab [1], who divided the industrial revolution into four main trends: unmanned vehicles, 3D printing, advanced robotics and new materials. In the paper we will focus on advanced robotics.

If we look at the history of the robotics development, we can observe that the increase of the functionality of robots causes the raise of the number of their possible applications in various fields of human activity. The creation of a robot was preceded by the idea of replacing a person in hard work, and the physical capabilities of the human body served as a model for them. The robot can be represented as a universal machine for performing mechanical actions. The functional diagram of the robot includes the executive system, the sensor system, the control device and the external environment.

Today, robots go beyond their limits and become flexible, mobile, and more intelligent. As part of Industry 4.0, robots have become the driving force of automation where it has never been before. Compared with pre-revolutionary production systems, where the human operator and robotic complexes are separated according to safety standards, production using advanced robotics and a collaborative system of human interaction — the operator and robot work together in a single working environment [2]. In the future, automation of processes in the field of logistics, health and utilities will be carried out by robotic systems.

The main field of application of robotics is industry. Technologies contributing to the improvement and automation of processes have changed. Progress in the field of robot sensors has made robots compact and more susceptible to the environment expanding the range of their tasks. Such robots are called collaborative robots. This type of robots is determined by compliance with the technical
specification of the ISO/TS 15066:2016 standard [3], in particular with safety measures when interacting with the robot.

This review deals with human-robot collaboration in an industrial context. Collaborative robots have become evidence of the emergence of a new generation of robots that will evolve with an orientation toward increasing interaction between humans and robots.

2. The shift to collaborative robots
Considering the robotics in general, we can distinguish three directions. The first direction is industrial robotics, in particular, these are industrial reprogrammable and multi-purpose manipulators programmed in three or more axes. In the workspace, an industrial robot can be fixed in a given place, but it can also be able to move to perform industrial automation tasks.

The second direction is collaborative robotics, as a progressive stage in the development of industrial robots. This is a new stage in the development of industrial robots, which assumes that they will interact very closely with humans and will be safe for them. These robots are equipped with a wide range of sensors and vision systems. For example, if a person enters the zone of action of such a robot, they will be able to change the algorithm of behaviour and will not harm the person. If it is a moving robot, then, getting into the trajectory of human movement, it must either stop or change its trajectory.

The next direction is service robotics, represented by mobile autonomous/semi-autonomous robotic complexes, including collaborative robot manipulators, used in various fields of human activity. These are robots that perform useful work for people and equipment, excluding industrial tasks of process automation.

According to the technical specification [3], when describing a collaborative robot, it is primarily about a collaborative working environment, and not just about security measures and sensors of a collaborative robot. This description of the collaborative working environment reveals the essence of creating a comfortable environment for human and robot interaction. A person is considered as a kind of mechanical colleague from the position of a collaborative robot, and the task of the robot is to help and assist in achieving the goal. This concept of the development of human-robot interaction is reflected in the paradigm of the fourth industrial revolution.

The idea of the Industry 4.0 paradigm is that an industrial robot can serve as a cooperative and auxiliary tool for humans in production. The main element of the paradigm is artificial intelligence, based on the “Internet of things”. The Internet of Things in its simplest sense, is a network of physical objects that interact with each other via the Internet [8–9]. Collaborative robotics and innovation change the business processes of modern industry, the integration of robots generally contributes to the computerization and automation of production leading to an understanding of the concept of “smart” production.

3. Safety issues and related risks for industrial human-robot collaboration
During the production operation, the robot and the person perform tasks simultaneously within the collaborative working space. This increased interaction and cooperation in the man-machine system has an impact on overall security. First of all, the security measures are focused on the person who is in the zone of the operational action of the robot. Further, in figure 1, we will consider the workspace where a human and a robot interact.

There are regulated security and protection measures that must be followed when organizing human-robot collaboration in accordance with [3]. But at the same time, these measures apply to collaborative robots of small and medium capacity. In the future, developers are considering the production of collaborative robots with a large payload. This will automate industrial production processes within the concept of Industry 4.0.
The main aspects of a collaborative robot joint work that meet the technical specification of ISO/TS 15066:2016 [3-7, 10] are as follows:

- “Safety-rated monitored stop” – robot stops when human-operator enters the collaborative workspace and continues when workspace free (allows for direct operator interaction with the robot system under specific circumstances).
- “Hand guiding” – robot movements are controlled by human-operator (operator uses a hand-operated device to transmit motion commands).
- “Speed and separation monitoring” – operator and robot system may move concurrently in the collaborative workspace.
- “Power and force limiting” – contact forces between human-operator and moving robot are technically limited to safe level (physical contact between the robot system and a human-operator can occur either intentionally or unintentionally).

The organization of effective interaction between a person and a robot at work may have certain risks of harming both the person and the robot. Let us consider the risks presented in table 1, which are described in detail in [10, 13].

Table 1. List of potential risks of hazardous from human-robot interaction during collaboration.

| Type of risks of hazardous | Description |
|----------------------------|-------------|
| Risk of hazardous from robot | • distance between human operator and robot in collaborative work space;  
• trajectory traversed by the robot and obstacles in the path of the robot;  
• the speed of movement of the human operator and the slow response of the robot;  
• psycho-physiological state of a human operator. |
| Risk of hazardous from the industrial process | • the duration of the process and the transition from one action to the next; |
Risk of hazardous from robot control system malfunction -

- lack of ergonomic solutions for operating activities and maintenance;
- the complexity of the task in the collaborative work space;
- human operator influence.

Special attention is paid to:

- error of the human operator during the operation of the robot and at the time of completion of operational actions;
- creating obstacles for the functioning of the robot sensors;
- malfunction at the control level and impact on the control system from the outside (cyber-attack).

The above list of possible harm to the human health of the operator and his safety is comparable to the current level of organized human-machine interaction. In the future, for safe and effective interaction, industrial collaborative robots should be equipped with integrated programs and additional sensors that will allow them to analyse, understand and predict human intentions in the collaborative work space [12].

4. Conclusion

In the future, the development of collaborative robotics in the industry will be expressed by the close interaction of man and robot. In such conditions, the working space of the robot will intersect with the personal space of a person. To ensure a safe and effective interaction between a human operator and a robot, it is necessary to consider a complex task with a multitude of factors influencing the performance of production tasks. Industry 4.0 changes the structure of production processes, and man becomes the centre of the industrial system. Thanks to the emerging favourable conditions, collaborative industrial robots will become significantly smarter, demonstrate the benefits of reliable and secure cooperation, and increase the productivity and efficiency of performing tasks.

The purpose of the subsequent research will be to determine the maximum positive effect of the interaction between humans and the collaborative robot in a collaborative working environment.

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