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GENERAL ENGINEERING AND MECHANICS

Comparative analysis of the advantages and disadvantages of collaborative robot control methods within Industry 5.0

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Industry 5.0 represents an evolution of industry in which robotics and automation focus on close collaboration between humans and robots [1]. This means that collaborative robots play a key role in Industry 5.0, and management methods must support their collaboration with humans. Analyzing publications, at this point in time there are the following methods for managing collaborative robots within Industry 5.0 [2–5]:

- programmable control: Robots can be programmed to perform various tasks. Industry 5.0 uses intuitive software tools to allow engineers and workers to customize and reprogram robots so they can interact with people and perform different tasks based on needs;

- Control using gestures and facial expressions: Collaborative robots can be equipped with systems for recognizing gestures and facial expressions. It allows operators and workers to control robots using gestures, facial expressions and voice commands;

- sensors and feedback: Robots are equipped with various sensors, such as cameras, lidars, touch sensors and others. They can use this information to detect obstacles, avoid collisions, and even respond to physical contact with a person;

- Machine Learning and Artificial Intelligence: With the advancement of machine learning and artificial intelligence, robots can learn in real time and adapt to new scenarios and tasks. They can analyze data, make decisions and optimize

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their actions depending on the context;

- safety systems: An important aspect of managing collaborative robots is ensuring the safety of workers and operators. Robots can be equipped with safety systems such as soft shells, collision sensors and emergency stop systems.

- collaboration systems: Robots can be integrated into collaboration systems, allowing operators and workers to interact with them on the job and perform tasks together.

For ease of analysis, we present the advantages and disadvantages of the above listed methods for controlling collaborative robots within Industry 5.0 in the form of Table 1.

Table 1

Comparison of the advantages and disadvantages of various methods of controlling collaborative robots [6-10]

Control method	Advantages	Flaws
Software control	<ul style="list-style-type: none"> - flexibility in configuration and reprogramming; - the ability to create a variety of programs; - task automation support 	<ul style="list-style-type: none"> - programming knowledge is required; - requires time to develop and debug the program;
Control using gestures and facial expressions	<ul style="list-style-type: none"> - natural and intuitive interaction; - minimizes the need for operator training 	<ul style="list-style-type: none"> - requires sensors for recognition of gestures and facial expressions; - limited set of available gestures and commands
Sensors and feedback	<ul style="list-style-type: none"> - allows robots to react to the environment; - obstacle detection and safe movement 	<ul style="list-style-type: none"> - limited recognition of difficult situations; - may require complex data processing algorithms
Machine learning and artificial intelligence	<ul style="list-style-type: none"> - adaptation to new scenarios and conditions; - ability to optimize production processes 	<ul style="list-style-type: none"> - requires a large amount of data for training; - not always able to explain decisions made
Collaboration systems	<ul style="list-style-type: none"> - the ability to work together between humans and robots; - expanding the functionality of robots in cooperation 	<ul style="list-style-type: none"> - requires coordination between human and robot; - may require additional integration with processes

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One drawback that may be common to all methods of controlling collaborative robots is the potential dependence on technical failures. Regardless of the control method chosen, robots may be subject to technical problems, including hardware failures, software errors, network failures, and other problems. These problems can cause interruptions, reduced productivity, and in some cases even pose a safety hazard to operators and others.

In addition, the complexity of the technical solutions used in each method can also be accompanied by high costs for development, maintenance and personnel training. Implementing and maintaining robot control systems requires specialists with the appropriate knowledge and skills, as well as investment in hardware and software.

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