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ROBOT MANIPULATOR CONTROL SYSTEMS COMPARISON WITHIN THE CONCEPTS INDUSTRY 5.0 AND INDUSTRY 4.0

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Abstract: The article explores the differences in approaches to control systems for manipulator robots within the concepts Industry 4.0 and Industry 5.0. The main requirements for classical control systems focused on automation and autonomy and collaborative systems that take into account interactivity and adaptability for close interaction with a person are analyzed. The comparative analysis highlights the advantages and challenges of each approach, suggesting directions for further developments in the field of adaptive and safe robotics systems.

Key words: Industry 4.0, Industry 5.0, Robot Control Systems, Manipulator Robots, Collaborative Robotics, Automation.

Introduction

In modern production conditions, the role of robotic systems is rapidly expanding, which determines the evolution of requirements for control systems for robot manipulators. The transition from the concept of Industry 4.0 to Industry 5.0 involves significant changes, in particular, the orientation towards a human-centric approach, the integration of intelligent systems and the consideration of the human factor in production processes [1]-[12].

While Industry 4.0 emphasizes autonomy, high speed and accuracy in performing routine tasks, Industry 5.0 focuses on ensuring safe human-robot interaction, adaptability and flexibility in performing tasks. This makes it possible to use different methods and approaches [13]-[30]. As new technologies pose the task of optimizing processes and increasing efficiency to a new level, there is a need to compare classic control systems for robot manipulators with innovative systems for collaborative robots focused on cooperation with humans. Such a comparison will allow us to better understand how the requirements for safety, intuitive control,

adaptability, and the ability to quickly reconfigure affect the design and operation of robot control systems in the context of Industry 5.0 [31]-[41]. Given the relevance of the development of human-robot collaborations, research in this area contributes to the improvement of production processes and the implementation of innovative solutions designed to increase the efficiency, flexibility, and safety of robotic systems in the modern industrial paradigm.

Related works

The concepts of Industry 4.0 and Industry 5.0 are widely used in modern production. Each of them has its own advantages and disadvantages. Many scientists consider them in their works. Let us consider some of these scientific works.

Kemendi, Á., and co-authors [42] explore what is meant by the term Industry 5.0 and how it differs from Industry 4.0. The research reveals the changing role of human resources management in the context of the necessary digital and computer competencies of society, highlights some security aspects, and looks at how enterprises, including SMEs, fit into Industry 4.0 and 5.0 era.

In [43] authors note that Industry 4.0 is considered to be technology-driven, whereas Industry 5.0 is value-driven. The co-existence of two Industrial Revolutions invites questions and hence demands discussions and clarifications.

The paper [44] argue that the most reasonable way to marry the two extremes of automation and value-based human-driven processes is to create an Industry 4.0 + Industry 5.0 hybrid, which inherits the most valuable features of both - efficiency of Industry 4.0 processes and sustainability of the Industry 5.0 decisions.

Scientists in [45] analyze the transition from Industry 4.0 to Industry 5.0. In this research work, through a critical literature review, they aim to provide adequate reasoning for considering Industry 5.0 as a framework for enabling the coexistence of industry and emerging societal trends and needs.

Raja Santhi, A., & Muthuswamy, P. in [46] outline the enabling technologies of Industry 4.0 and conceptualizes how they would act as the foundation for the fifth industrial revolution and the prospective technologies of Industry 5.0, their potential applications from the perspective of industry leaders and scholars and conceptualizes how they can overcome the challenges of Industry 4.0.

Zizic, M. C., & et al. [47] note that Industry 5.0 is complementing the existing Industry 4.0 paradigm with the orientation to the worker who has an important role in the production process, and that role has been emphasized during the COVID-19 pandemic.

The study [48] presents a comparative bibliometric analysis to show the connection and differences between Industry 4.0 and Industry 5.0 and their implications for smart logistics.

So we see that there are many works devoted to the analysis of Industry 4.0 and Industry 5.0. Further in this article we present our comparison of these concepts from the point of view of robot control.

Robot control systems research

Currently, the definitions and requirements for control systems for collaborative robot manipulators used in Industry 5.0 are governed by ISO 10218-1:2011 and ISO/TS 15066:2016, developed by the International Organization for Standardization (ISO) in Switzerland. ISO 10218-1:2011 describes general requirements for the safe integration and operation of robots in the human workspace, while ISO/TS 15066:2016 provides detailed guidelines for physical interaction between humans and robots, including levels of permissible contact and effort. In the context of classic robot manipulators used in Industry 4.0, ISO 10218-1:2011 is also applicable, specifying basic requirements for autonomous robotic systems, including safety and reliability. Another important standard is ISO 8373:2012, which regulates terms and definitions related to industrial robots. These standards are the basis for the development of control systems and apply to robots used in automated manufacturing environments, establishing international requirements for the safety, integration and operation of both types of robotic systems.

Let us consider the main concepts and differences in control systems for collaborative robot manipulators within the framework of Industry 5.0 and classic robot manipulators within the framework of Industry 4.0.

The control system for a collaborative robot-manipulator is a system that ensures safe, intelligent and flexible interaction between a robot and a person in a shared workspace. Its key requirements are:

- safety for a person nearby;
- the ability to learn and adapt to new tasks through intuitive programming;
- flexibility and adaptability in performing tasks taking into account the human factor.

The control system for a classic robot-manipulator within Industry 4.0 provides automated performance of repetitive tasks with high accuracy and speed, but mostly in an autonomous mode, without the need for direct interaction with a person. The main requirements for such a system are:

- high accuracy and speed of task performance;
- stability and reliability when performing routine operations;
- autonomy and minimal dependence on a person.

To better understand the differences in the requirements of control systems for collaborative robot manipulators within the concept Industry 5.0 and the classic robot manipulator (Industry 4.0), we will conduct a comparison, the result of which is presented in Table 1.

As can be seen from Table 1, the control systems of collaborative robot manipulators within Industry 5.0 differ significantly from the classic control systems typical for Industry 4.0.

Table 1: Comparison of requirements for control systems for collaborative robot manipulators within the concept Industry 5.0 and classic robot manipulator (Industry 4.0)

Requirements	Collaborative robot manipulator (Industry 5.0)	Classic robot manipulator (Industry 4.0)
Safety	High level, ensuring safety for humans	Mostly in enclosed spaces, minimal interaction requirements
Adaptability	Ability to change tasks in real time	Limited; focus on routine, unchanging tasks
Intuitiveness	Training support, including through HMI interfaces	Requires programming knowledge and prior setup
Execution speed	Moderate (focus on security and flexibility)	High to meet production requirements
Dependence on a person	Increased; takes into account the human factor	Minimal, autonomous operation without human intervention
Control technologies	Intelligent systems, AI, security sensors	Classic controllers, PLCs, high-precision programming
Flexibility in use	Enhanced; support for various scenarios	Low; hard scenarios, pre-programmed

The main focus in collaborative systems is on ensuring safety, adaptability, intuitiveness and flexibility, which allows robots to effectively interact with humans in a shared workspace. These systems also support real-time learning, which is important

for dynamic production environments. In contrast, classic robots are oriented towards autonomous operation with a focus on high accuracy, speed and stability, which allows them to effectively perform routine tasks, but limits the possibility of interaction with humans. This also confirms the need for intuitive HMI interfaces and artificial intelligence technologies in Industry 5.0, which help to quickly reconfigure tasks. A comparison of the percentage of influence of the control system requirements for the collaborative robot manipulator (Industry 5.0) and the classic robot manipulator (Industry 4.0) is presented in Figure 1.

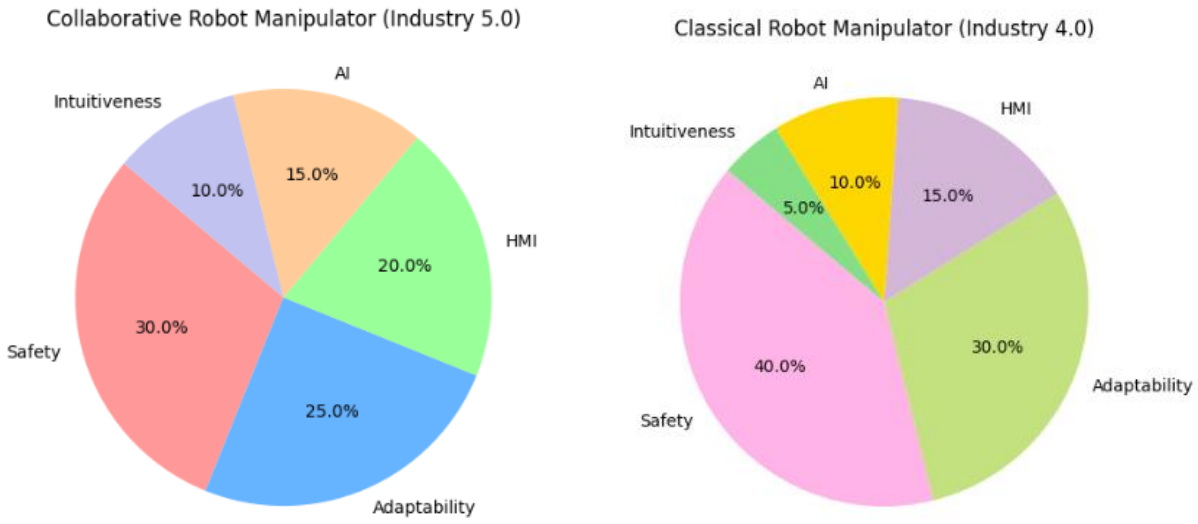

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Figure 1: Comparison of the percentage of influence of control system requirements for collaborative robot manipulator (Industry 5.0) and classic robot manipulator (Industry 4.0)

Based on the research conducted, it is possible to compare the basic parameters of the requirements of Industry 5.0 and Industry 4.0, which is presented in Table 2.

Table 2: Comparison of the basic parameters of the requirements of Industry 5.0 and Industry 4.0.

Parameter	Industry 5.0 (Collaborative Robots)	Industry 4.0 (Classic works)
Purpose	Human-centricity, human-robot interaction	Full automation, minimal human involvement
Focus	Security, integration into a shared workspace	Speed, accuracy, process stability

Control interface	HMI, intuitive and intelligent interfaces	Programmable controllers, little interactivity
Adaptability	High, on-the-job learning	Limited, requires reconfiguration
Technologies	AI, sensors, learning interfaces	Classic PLC technologies, mechanical automation

Thus, Industry 5.0 is focused on creating interaction between a robot and a person, which requires new control systems that are adaptive and safe to use, while Industry 4.0 focuses on maximally autonomous performance of tasks with high accuracy and stability in production conditions.

Conclusion

In today's technological development, the differences in approaches to robot control systems between Industry 4.0 and Industry 5.0 are becoming especially important for the effective integration of robotic solutions into production. Industry 4.0 focuses on automation and precision, which involves the use of classic robots controlled by systems focused on stability, autonomy and productivity. These systems are capable of performing repetitive tasks with high speed and precision, which meets the requirements of mass production, but limits their adaptability to non-standard situations. In contrast, Industry 5.0 introduces the concept of human-robot cooperation, requiring new approaches to flexibility, safety and interactivity of control systems. Collaborative robot manipulators that meet these requirements must take into account the integration of artificial intelligence to adapt to changing conditions and the possibility of intuitive communication with a human operator. The analysis shows that to implement the concepts of Industry 5.0, it is necessary to introduce technologies that will ensure a higher level of integration between man and machine, while Industry 4.0 is focused on minimizing human intervention. Taking into account these different approaches, a comparative analysis of the requirements for control systems allows us to identify the main directions of technology development aimed at creating adaptive, safe and highly efficient robotic solutions.

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