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SAFE WAREHOUSE IN COLLABORATIVE ROBOT TECHNOLOGIES

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Summary. *Industrial robots have gained significant application and popularity in modern industries worldwide due to their productivity, reliability, efficiency, and ability to perform hazardous operations that pose or potentially pose a risk to people. However, there are cases when classic industrial work cannot be used, and human work becomes the only alternative in production. With the continuous rapid development of technology, a new type of industrial robot has emerged, namely collaborative industrial robots. The peculiarity of the latter lies in the functional and hardware capabilities of interacting with a person and mutually complementing him, performing joint technological operations. These capabilities are achieved with the help of advanced technologies such as technical vision, artificial intelligence, signal processing technologies from various sensors, etc. The use of collaborative industrial robots in modern production, together with humans, poses many problematic issues related to human safety in production processes. A brief analysis of the available information sources indicates the relevance of the above question and the variety of approaches to its solution and research. However, there are currently no comprehensive solutions, and there is fragmentation regarding human safety in collaborative robotic technologies. Existing gaps in ISO safety standards are highlighted, which do not fully address the known safety components of human collaboration and collaborative industrial robots. The essence of the definition of the safety component in collaborative robotic technologies is highlighted as a complex concept that involves the use of hardware, software, ergonomics, and other components to support and ensure human safety in the conditions of technological collaboration. Attention is focused on improving the process of training personnel and updating technological equipment for safety efficiency in collaborative robotic technologies. Recommendations that would complement the existing ISO standards are proposed. The above is defined as a promising direction of research in the field of collaborative robotics.*

Key words: *industrial robot, collaborative robotics, safety, ISO standarts.*

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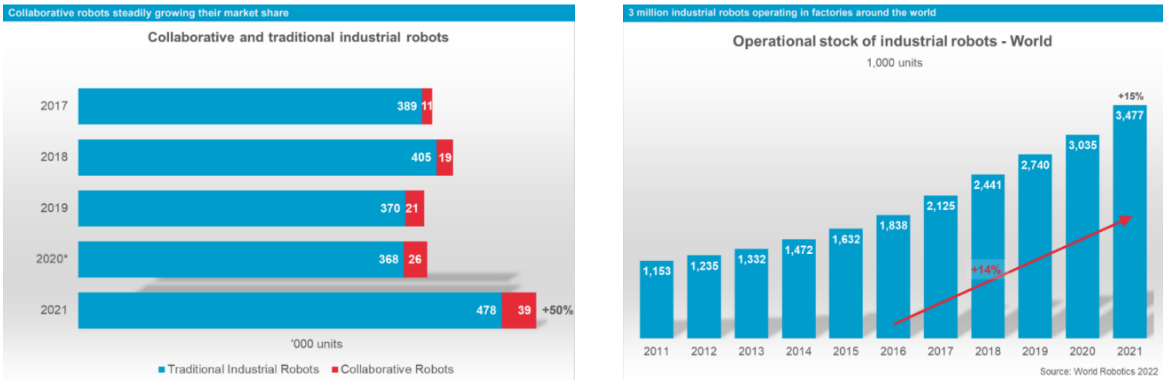
Statement of the problem. In recent years, the use of industrial robots (RP) in various fields of production has been constantly increasing around the world (Fig 1) [1]. It is because modern PRs are productive, reliable, economically viable means of flexible automation and can perform such types of work that are dangerous for people to perform. However, there are industries where «classical» PR is impossible, and human labor is the only option for ensuring the execution of the technological process. The development of technologies, robotics, and the concept of the 4th industrial revolution Industry 4.0 [2] created the prerequisites for the growth of the production and use of a special type of industrial robots, namely collaborative industrial robots (CIR). The main feature of CIR is due to functional and hardware capabilities to interact and perform joint technological operations with a person, complementing each other. The above capabilities of CIR are achieved due to the use of modern technologies such as technical vision, artificial intelligence, etc.

The direction of development of modern industrial robotics in terms of its collaborative nature assumes an ever-increasing role of man in the implementation of relevant technological processes. The above, together with the factor of growth in the use of CIR in collaborative robotic technologies (CRT) in various industries [1], pose many problematic issues and tasks regarding human safety in productions where a person performs joint operations with PR and/or CIR or interacts with CIR.

An example of technologies potentially dangerous for humans can be electrochemical coating technologies (cadmium plating, nickel plating, alerting, etc.) of functionally important surfaces of parts of equipment in the oil and gas industry, painting technologies, various assembly processes, and others.



a b

Figure 1. Information on the growth of the use of PR and CIR: a) – global increase in the production of PR; b) – global increase in the use of PR and CIR [1]

Analysis of the available investigations. The papers The work analyzes the available information sources devoted to the issue of the security component in the CRT, including safety standards, in particular international ISO standards, as well as scientific publications and studies related to security in the CRT.

In work [3], the methods of compliance with safety in CRT, described in ISO 15066 and ISO 31000 [4–5], are considered. This work highlights one of the simplest approaches to improving human safety in CRT: using a safety net (safeguard, Fig 2) in CRT. The article highlights the assessment of the existing developments in developing safety nets in the CRT. It proposes a framework for coordinating the design of safety nets during design with risk assessment. This work reveals the standard's lack of clarity and shortcomings in the standard [4]. It proposes a framework based on known standards [5] to guide developers and users in choosing security measures for CIR applications.

Figure 2. Protective fencing in robotic technologies, including collaborative ones

The standard [4] provides recommendations that developers and users should consider when implementing security measures in systems with collaborative devices. However, this standard does not provide clear guidance for developers or users on selecting security measures from the entire list of available options, just as it does not specify the criteria for selecting these measures.

Articles [6–7] highlight new approaches to improving safety control in the CRT, taking into account the requirements of international safety standards. The authors offer an online system for testing the intersection between the limiting volumes of the CIR, which includes the calculation of the dimensions of these volumes in real-time based on the speed of movement of the links of the manipulation system (MS) of the CIR along a given trajectory, which allows you to check compliance with the safety requirements for stopping constructive elements of the CIR. The proposed approach allows for online assessment of safe zones following the technical requirements of specific technologies. It solves many problems associated with collaborative robotics, which involve compliance with the safety requirements specified in the ISO as mentioned above standards.

Manuscripts [8] indicates the current requirements of the Finnish industry regarding the use of CIR. In addition to the search for new methods of human cooperation with CIR, one of the main problems remains the problem of production safety. The article focuses on the fact that there is a general problem of insufficient awareness of CIR, which should increase scientific activity in this direction.

An overview of the main modern safety systems used in production environments with CIR, which contribute to the achievement of safe joint work between humans and CIR, is covered in the article [9]. The authors of this article highlight methods for assessing and assessing injuries in human-robot collisions, mechanical and software devices designed to minimize the consequences of human-robot collisions, collision detection systems, and strategies to prevent collisions or methods to minimize unwanted consequences when they occur.

Article [10] briefly overviews how CIR is used to support workers in an Industry 4.0 production environment. The authors emphasize that CIR supports workers in physical and cognitive tasks. Still, the interaction between a person and a robot can also have certain risks if human factors are not well thought out in the interaction process. Also, the article [10] highlights the change in the human role in production with CIR and relevant issues regarding production safety.

[11] provides a systematic review of available information sources to determine a number of problematic issues regarding the safety of the use of CIR. It states that the criteria for labor safety are of decisive importance when implementing CIR in production. The article emphasizes the need to assess the modern level of development of safe and ergonomic CRTs. The main research topics considered in the latest scientific literature on safety and ergonomics (or human factors) for industrial joints, i.e., collaborative robotics, are identified and classified.

Article [12] points to the diversity of CIR applications, which raises the issue of terminology and the content of general definitions, safety rules when working with CIR, and programming methods that ensure safe cooperation between humans and CIR, execution of safe (non-collision) trajectories, etc. The authors systematically consider and offer options for defining the main terms characteristic of CRT, making it possible to generalize and systematize commonly accepted names in collaborative robotics.

The issue of safety in the context of structurality and systemicity is partially covered in work [13], where it is proposed to introduce an additional (intermediate) level into the structural system of the automation pyramid. Additionally, the introduced sub-level details from the point of view of the systemic nature of the connection between the equipment, the CPR, and the person, which partially details, including the problem of the safety component.

The generalization of the brief analysis of available information sources indicates the existing multifaceted security problem in CRT, which is only partially solved by researchers and engineers. The basis of the safe joint work of a person and CIR is a variety of measures, starting from fencing nets, ending with software restrictions during the operation of CIR and compliance with the recommendations of various recognized safety standards ISO 15066 [4], ISO 31000 [5]). Some articles emphasize a person as a new component of CRT in production and a change in his primary role, which determines the possible direction of further research on developing recommendations for improving human safety in CRT.

The Objective of the work is to critically analyze available information sources regarding the issue of the security component in the CRT and its generalization with the highlighting of certain shortcomings in the context of this problem.

Statement of the task. Based on the analysis of available information sources, a study has been conducted on the generalization and systematization of recommendations and requirements for ensuring and observing safety at work using CPR in cooperation with a person. However, there is currently no general standard, methodology, or approach for the comprehensive provision of safety components in the absolute understanding of the meaning of this concept for CRT.

Results of the study. The concept of «safety components» in this work refers to such components in the CRT, which provide for the provision and observance of safety during the joint work of a person and a CPR due to the use of special CPR hardware, CPR software settings, ergonomics and planning of a joint working space of a person and a CPR, compliance with the safety rules for the work of people with CPR, etc.

The hardware in the CPR involves using various sensors, which are structurally placed, as a rule, in the joints of the links of the CPR MC and which respond to external action, for example, to the action and/or the human body. These can be sensors for the presence of an object in a defined area or sensors that respond to changes in the strength of currents in the windings of electromechanical systems of robots (electric motors) during contact or non-contact contact of a person with CIR, etc. Thanks to the development of microprocessors and other technology, the speed of reaction and the accuracy of measurement of certain parameters of the contacts of the human-CIR system makes it possible to better respond to external actions of the CIR, for example, in case of collisions during trajectories.

Modern software, namely advanced programming languages and their interpreters, allow you to quickly and efficiently process input signals from sensors and perform appropriate corrective actions, for example, stopping the operation of the CIR or slowing down the movement of the links of the CIR manipulation system. Also, modern programming languages make it possible to use technical vision and artificial intelligence to ensure human labor's safety with CIR (Fig 3).

The most common options for using the latter are the reaction of the CIR in the event of a person leaving his working area, where there is a possibility of a collision with the CIR, namely stopping the CIR or moving the final element of the CIR MC to a place that is safe for the person.

Ergonomics of the workspace is also an important safety component, which is currently quite effective. The correct location of the equipment and the organization of the worker's workplace prevent the occurrence of many dangerous situations for a person and also prevent emergencies that can lead to damage to the CIR and other technological equipment. In these cases, a protective or fence net (safeguard) has proven itself well as a simple and effective engineering solution that prevents many dangerous situations for people. The formation and observance of safety rules when working with CIR aim to reduce the probability of accidents, injuries, or emergencies due to human fault. The above is achieved by conducting briefings and training employees on safe work with CIR.

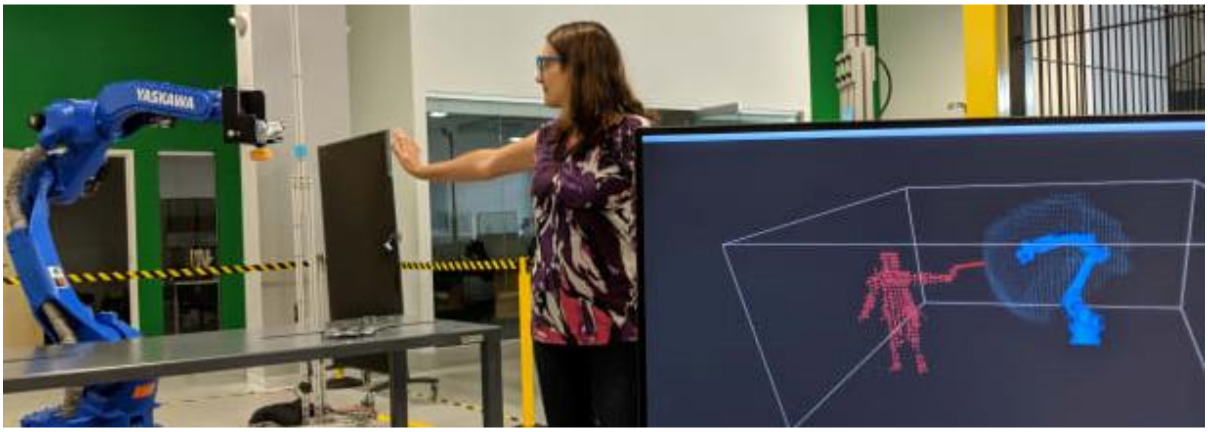


Figure 3. Simplified illustration of the use of technical vision in collaborative robotic technologies [14]

According to the above analysis of available information sources, gaps and incompleteness in ISO safety standards related to CIR have been determined.

One of the main shortcomings of the ISO standards is insufficient attention to the safety of joint operations of a person and a CIR, which can lead to potentially dangerous situations where a person and a robot are in the same working space (work zone) without the necessary safety measures. Inadequate control in this aspect can create risks for the safety of personnel and cause possible injuries or accidents.

Moreover, some factories did not comply with safety requirements during the implementation of CRT [11–13]. This is usually due to the complexity of implementing safety standards, insufficient qualification of personnel, or untimely updating or maintenance of technological equipment and software.

The problem of the safety of the joint work of a person and CIR arises for various reasons. One of them is the processes in the workspace shared by the person and the CIR or in the work area, which require precise coordination between the person and the CIR since the person's role is somewhat changed compared to «classic» robotic technologies. For example, there may be a risk of collision or entrapment of a person due to insufficient understanding of the robot's movements. One of the reasons for this is the existing problem of insufficient awareness and training of personnel regarding safety when working with CIR. Lack of proper training can lead to misunderstanding safety rules, improper use of equipment, or improper response to potentially dangerous situations.

There are deficiencies and gaps in CRT's safety components and existing ISO standards. The conducted analysis of information sources showed that ISO standards fragmentarily highlight general concepts, approaches, and recommendations regarding the issue of human safety in CRT. Also, some of the ISO standards partially repeat the information covered in each of them regarding the description of the safety components of the CRT.

Table 1 provides information on the availability of the main safety components of CRT in ISO standards. Here, the symbols ✓ mean the presence of the corresponding analysis components, and the absence of these symbols means their (components) absence.

The above information in Table 1 confirms the previously formed and stated problems regarding the insufficient processing of human safety issues when interacting with the CIR. Only two of the five standards, covered incompletely, provide recommendations for ensuring and maintaining safety in the workplace where CRTs are used.

Table 1

Safety components in ISO standards

Sources / Safe CRT components	ISO 10218-1:2011 [15]	ISO 10218-2:2011 [16]	ISO/TS 15066:2016 [4]	ISO 13482:2014 [17]	ISO 31000 [5]
Risk management and risk estimation		✓	✓	✓	✓
Measures to ensure security		✓		✓	
Recommendations for planning a safe production environment	✓		✓		✓
Security verification and validation	✓	✓		✓	

One of the ways to solve the problems as mentioned above is the development of new safety standards that would minimize, and ideally reduce to zero, the probability of dangerous situations. These standards should ensure safety in the conditions of joint work of a person and CIR, considering the known potential risks.

Also, providing adequate safety training for personnel when working with CIR is crucial. It includes safety training, safety briefings, familiarization with emergency response procedures for typical situations, and CIR teamwork skills. Briefings and training should be systematic, regular, and meaningful so that personnel improve new knowledge and skills on safety issues in implementing CRT.

In addition, the constant updating of technical equipment and its software is an important aspect of ensuring safety in collaborative robotic technologies. Technological progress is developing rapidly, so it is necessary to periodically check and update equipment concerning safety requirements. Software updates will help fix bugs and vulnerabilities that can affect the security of your production environment.

Conclusions. The work highlights the issues of the safety component in the CRT, which is complex and consists of the insufficient processing of safety issues in international ISO standards and other information sources, the emergence of new and complex technologies, changes in the role of humans in collaborative robotic production, and the lack of a single comprehensive approach to solving safety problems issues in the CRT.

An analysis of available information sources regarding the issue of the safety component in the CRT was conducted, which indicated the relevance of the existing problem and its active discussion in scientific and engineering circles. On the one hand, researchers fragmentarily solve various security problems in CRT. On the other hand, there is no comprehensiveness and systematic solution to existing security problems in regulatory documents, first of all, in existing ISO standards.

The basis for solving the most common safety issues is the recommended information from ISO standards, which, in addition to definitions and terms, provide practical advice on the use of CIR in cooperation with a person. The disadvantage of the latter is the lack of content, and often the absence of recommendations for their use, the insufficient informativeness of the recommendations, and the presence of gaps in the safety of CRT in various industries. The generalizations made based on the highlighted content of problem-oriented informative sources clearly emphasize the existing problems of collaborative robotics regarding the safety of human joint work and CIR.

The authors also see the development of recommendations as promising in the future, which would systematically fill the gaps in the existing ISO standards regarding the safety of human interaction and CIR.

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БЕЗПЕКОВА СКЛАДОВА В КОЛАБОРАТИВНИХ РОБОТИЗОВАНИХ ТЕХНОЛОГІЯХ

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Резюме. *Промислові роботи набули значного обсягу застосування та популярності на сучасних виробництвах по всьому світу завдяки своїй продуктивності, надійності, ефективності та можливості виконувати небезпечні операції, які несуть або потенційно можуть нести ризик для людей. З постійним стрімким розвитком технологій з'явився новий вид промислових роботів, а саме колаборативні промислові роботи. Застосування колаборативних промислових роботів на сучасних виробництвах разом з людиною ставить ряд проблемних питань, що пов'язані з безпекою людини у виробничих процесах. Стислий аналіз доступних інформаційних джерел вказує на актуальність вищевказаного питання та різноманітність підходів щодо його розв'язування та дослідження. Однак наразі відсутні комплексні* *рішення та присутня фрагментарність щодо забезпечення безпеки людини в колаборативних роботизованих технологіях. Розглянуто проблеми безпеки людини, пов'язані з використанням колаборативних технологій. Висвітлені існуючі прогалини в безпекових стандартах ISO, які не повністю враховують відомі компоненти безпеки спільної роботи людини та колаборативних промислових роботів. Висвітлено сутність визначення безпекової складової в клаборативних роботизованих технологіях як комплексного поняття, яке передбачає застосування апаратної, програмної, ергономічної та інших складових для підтримки та забезпечення безпеки людини в умовах технологічної колаборації. Акцентується увага на необхідності покращення процесу навчання персоналу та оновлення технологічного обладнання для ефективності безпеки в колаборативних роботизованих технологіях. Запропоновані рекомендації, які б доповнювали існуючі ISO стандарти щодо безпекової складової колаборативних технологій. Вищевказане визначено як перспективний напрямок досліджень у галузі колаборативної робототехніки.*

Ключові слова: *промисловий робот, колаборативна робототехніка, безпека, ISO стандарти.*

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