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# IMPLEMENTATION OF SAFETY SYSTEMS IN APPLICATIONS WITH COLLABORATIVE ROBOTS

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***Abstract:*** *Currently, collaborative robots represent a viable alternative to improve the efficiency, effectiveness and quality of a serial manufacturing process. They can be found in more and more manufacturing flows both in the automotive industry and in other industries. Collaborative robots can be integrated and used in numerous manufacturing processes. Although collaborative robots were created to share the work environment with the operator, there are applications where collaborative robots operate tools at high speed in the manufacturing flow. Due to this aspect, it was necessary to think of and implement a safety system that will additionally protect the human when interacting with the collaborative robot. The scientific work presents a safety system that can be implemented in applications with collaborative robots.*
***Keyword:*** *collaborative robot, automotive, safety, automation, systems, electrical solutions.*

## 1. INTRODUCTION

In 2022, collaborative robots are implemented on a larger scale in the automotive industry and other existing industries.

Collaborative robots are recommended to be implemented in areas where the repeatability of operations is high. They increase the efficiency, effectiveness and quality of the manufacturing process into which they are integrated. Also, collaborative robots represent a viable alternative for the future in case of personnel crises.

Collaborative robots were designed to share the workspace with operators or workers. They are provided from a constructive point of view, as well as from the point of view of the program with systems that realize the emergency stop of the collaborative robot in case of a collision and possibilities of limiting the speeds and other capabilities at which it could operate.

However, there are applications where the collaborative robot must operate certain tools that are not collaborative and can put the operator's life in danger. Also, if an increase in productivity is necessary to satisfy the client's requirements, the collaborative robot must operate at high speeds. In such applications or situations, it is mandatory to implement an additional safety system to protect the operator during the interaction with the collaborative robot.

This safety system is composed of several electrical components. The components of this system will be presented in the chapters of the scientific work. Also, this scientific work will present the principle of the electrical operation of each component in this system, the integration method of these components and the electrical interface of the collaborative robots from Universal Robots.

During the scientific paper, real existing alternatives on the market will also be highlighted that can be used in an application following those presented. The authors consider the fact that human safety, regardless of the situation, is a priority.

Thus, because collaborative robots are implemented on a large scale, the authors considered it opportune to research a system whose main role is the additional protection of humans following the implementation of an application with collaborative robots.

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## 2. COMPONENTS OF THE AUXILIARY SAFETY SYSTEM EXISTING AND USED IN APPLICATIONS WITH COLLABORATIVE ROBOTS

Human-robot interaction could also have some risks if human factors are not well thought through in the process [1]. Auxiliary safety systems have the role of additionally ensuring human safety. Auxiliary safety systems make human-robot interaction possible by certifying that the collaborative robot will stop every time the operator is in its vicinity.

The existing safety devices that make it possible to achieve this aspect are:

- Perimeter scanners;
- Safety barriers;
- Safety PLC;
- Safety relays.

The safety systems or articles are distinguished by their yellow colours, this aspect is also observed in figure 1.


**Fig. 1.** Safety devices used in the integration of collaborative robots

In human-robot collaboration, automatic safety controllers need to be implemented [2].

The safety devices have this colour to be easily observable in case it is necessary to activate them. The reset button does not have to be yellow because it has no direct role in the safety shutdown of the application. These can be found either in electrical panels, for example, the PLC or safety relays, or in the production line, for example, perimeter scanners or safety barriers.

The most common suppliers that provide such articles are Sick AG and Pilz GmbH & Co. KG.

Also, other auxiliary devices make it possible to stop the application in case of malfunctions and restart it:

- Emergency buttons;
- Reset buttons.

When humans physically interact with collaborative robots, they must be limited in terms of power and strength [3].

Auxiliary safety systems have the role of improving the safety of the operator or the worker who operates the production line.

Even if collaborative robots are built to share the work environment with the operator, it is often required, due to the cycle time they must achieve, to work at very high speeds. Also, there may be a situation where the collaborative robot will work with dangerous tools for the operator. Thus, collaborative robots could seriously injure a person who will collide during the process until they stop. To prevent this aspect, it is recommended to install and use an auxiliary safety system.

## 3. THE ELECTRICAL FUNCTIONING PRINCIPLE OF THE AUXILIARY SAFETY ELEMENTS USED IN THE PRODUCTION AREA

One of the biggest challenges is finding solutions regarding personnel safety [4].

The safety devices work at 24 V continuous voltage. This is both the supply voltage and the control voltage. This is the voltage at which most devices or sensors are operational in the automotive industry.

At this voltage, human life is not endangered when it encounters the power supply circuit. Thus, the person can come into direct contact with the powered wires without feeling any electric shock. Another plus in the use of this voltage is the fact that its use leads to the elimination of electrical fuses from the system. Due to this aspect, the elimination of some of their replacement costs over time is achieved.

The direct voltage of 24 V is usually obtained by transforming the alternating voltage of 230 V. This aspect is achieved using a source connected to the electrical network of an alternating voltage of 230 V, which will be transformed into a direct and reduced voltage of 24 V. The voltage can be lowered utilizing a transformer that operates at the frequency of the alternating voltage of 50 Hz, existing in the source, and then the current is transformed from alternating to direct through the rectifier or rectifier bridges and a capacitor.

Also, the voltage can be lowered utilizing a switching source (Switched Mode Power Supply, abbreviated SMPS) in which a high-frequency transformer (hundreds of thousands of Hz), one or more transistors (depending on the circuit used) is used, rectifier diode and a capacitor [5].

The following items can be founded in the electrical supply and management panel of the safety devices:

- The general button for starting and stopping the voltage, known as Main Switch;
- An automatic fuse of 6 amperes;
- Single-phase source output 24 V direct voltage with supply at 230 V alternating voltage;
- Power terminals for safety devices;
- Terminals for distributing signals to safety devices;
- Terminals for electrical grounding;
- Safety PLC with electrical connectors and card with memory chip;
- Output safety relays.

Such an electrical panel can be observed in figure 2.

**Fig. 2.** Electrical panel for controlling the auxiliary safety system in applications with collaborative robots

Thanks to this system, humans can perform different operations in parallel with the collaborative robot [6].

Following the implementation of such a system, it will have to be validated through a risk assessment. [7]

In the example shown in figure 2, the general switch button has the role of switching the voltage on and off. It has two positions to turn on or off. There are such buttons that allow them to be closed and locked with a padlock. Locking with a padlock is done by the technical staff when they perform maintenance work on the electrical system or the equipment. The technician switches the panel button to the voltage off position, locks the system with a padlock, and the unlocking key remains with it until the maintenance work is completed. Basically, this is a way of preventing work accidents because it can happen that someone else turns on the button during the execution of the works.

The automatic fuse of 6 amperes has the role of protecting the power supply and the rest of the circuit in case of variations in the electric current or in case of a short circuit. This will automatically disconnect the system from the electricity supply if there is a consumption greater than 6 amperes.

The single-phase source has the role of reducing the voltage from 230 V AC to 24 V DC and transforming the alternating voltage into direct voltage. Practically, from this source, the power supply of the safety devices existing in the system will be further distributed, such as safety PLC, relays, electrical distribution terminals, safety scanners, safety barriers, safety buttons and system reset buttons safety.

Power terminals make a bridge between the wires coming from the power source and the power wires of the safety devices that need to be powered. On this type of terminal, there are two connection areas: an area where 24 V (+) is connected and an area where 0 V (-) is connected. The wires of the devices must be tied very carefully so that they are not fed in reverse. They must not come into contact if there is voltage in the system because this aspect will lead to a short circuit. Also, if one of the wires is not connected, the circuit will not be closed, and this aspect will lead to a lack of power to the devices in the circuit.

The terminals for distributing the signals to the safety devices are functionally similar to the power terminals. The difference is that from a constructive point of view they have only one connecting area. They form a bridge between the wires coming from the safety devices, for example, the safety perimeter scanner or the safety barrier, and the wires leading to the safety PLC inputs. These wires are under the command voltage of 24 V (+) direct voltage and come from safety devices such as safety barriers, perimeter scanners, and system reset buttons.

The grounding terminals make it possible to create a bridge between the grounding wire coming from the power source and the wires connected to the electrical panel. Grounding has the role of protecting people from electric shock. If one of the live wires touches the conductive surface of the electrical panel, then the contact between the earth and the live wire will lead to an increase in the current in the circuit to a value greater than 6 A, this being the maximum limit of the automatic fuse in the system. This aspect will lead to the disconnection of the electric current supply automatically by the safety until the problem is fixed, and it also makes it possible for the defective current to flow to the ground.

The PLC is a programmable logic controller. This, being safety, has certain additional safety functions to control the connected safety devices. Through it, logic gates are made according to which the PLC will control the entire system. Therefore, it can be said that the safety PLC is the brain behind the control of safety stops or starts of collaborative robots. It has multiple inputs and outputs for electrical signals. Depending on the model, it can also have ethernet connections through which it will continue to communicate with the safety devices. The safety PLC receives the signals from the signal distribution boards from the safety devices through the assigned inputs, and depending on the program, it can control the behaviour of the robots through the electrical outputs. Both the behaviour of the inputs and the behaviour of the electrical outputs can be programmed. The safety PLC can control the behaviour of the robots in this way:

- safety stop collaborative robots if one of the perimeter scanners detects the presence of a person in the vicinity of the robot. The application will automatically restart from the left point when the operator leaves the working area of the collaborative robots;
- emergency stop collaborative robots in case of pressing an emergency button.

This aspect takes place by interrupting the 24V DC voltage. Through this aspect, the safety PLC interrupts the supply of the safety inputs of the collaborative robot. Depending on the area where the PLC will stop the power supply, the robot will react by stopping for emergencies or safety.

The safety PLC also has certain electrical connectors that clip into dedicated areas. These connectors are used for mounting and fixing the electrical wires necessary for its power supply or the inputs and outputs of the necessary electrical signals.

The memory chip card has the role of saving the programmed application. The memory card is chosen according to the complexity of the programmed application.

An important aspect to remember is the fact that it is a safety application, the communication between safety devices, safety PLC and collaborative robots must be done through two channels. This aspect requires that the safety devices send signals of 24 V direct current (+) on two separate wires. The safety PLC will receive them and interpret them to send further signals on two separate wires, through its outputs, at the same electrical potential. Collaborative robots will receive the signals from the safety PLC, they have two inputs for the emergency stop and respectively two inputs for the safety stop. If one of the wires stops working due to its damage, the application will stop because one of the safety devices is malfunctioning and this defect endangers the safety of the operator.

The safety PLC works at a voltage of 24 V DC.

Output safety relays have the role, in applications with collaborative robots, to interrupt the power supply to the emergency circuit of the robot. In some cases, it can be connected to the safety PLC through quick clamps, and its power supply and control are also being carried out by the safety PLC. It can also be used to interrupt other safety circuits in other applications.

The safety devices work at a control voltage of 24 V direct voltage. They work on two channels or two electrical wires to ensure human safety. The safety devices that will not be found inside the electrical panel are:

- Safety perimeter scanners;
- Safety barriers;
- Emergency buttons;
- Emergency system reset buttons.

The safety perimeter scanner has the role of detecting the access to the working area of the human collaborative robots. It transmits this aspect to the safety PLC on two channels. The safety perimeter scanner has a total of 8 connection wires, in the case of the microScan 3 Core I/O model from the supplier SICK, with the following colour codes, namely:

- Brown, to which the +24 V DC power supply will be connected;
- Blue, to which 0 V DC will be connected;
- White, safety channel number 1;
- Black, safety channel number 2;
- Pink represents an input/output configurable by the programmer of the perimeter scanner. As an input, it can be programmed to receive a signal by which it can be reset, a signal by which it enters sleep mode or a signal for automatic start. As an output, it can be programmed to notify using an electric signal that the detection surface is contaminated and must be cleaned, that a reset is necessary, an error exists;
- Violet, has the same function as the pink thread;
- Grey, has the same function as the pink thread;
- Orange, on which the grounding will be connected.

The safety perimeter scanner can be functional by using 5 wires. It is important that the scanner is powered by a 24 V DC source and the grounding is connected. Due to this aspect, the first wires to be connected, as mentioned, will be the brown, blue and orange wires. The white and black wires that will interrupt the 24 V DC electric signal in case of detecting a person in the working perimeter of the collaborative robot, will be connected in the signal distribution terminals from the safety devices to the safety PLC.

If there is no safety PLC available and it is needed to use only one perimeter scanner, the signal must first be passed through a relay, because the voltage of the perimeter scanner on the two channels is variable. This aspect will affect the functionality of the robot. The pink, purple and grey wires are optional depending on the desire of the integrator, the application can also work without connecting them. The safety perimeter scanner can be mounted both horizontally and vertically. Its safety and detection perimeter can be programmed.

The perimeter of the scanner must not be obstructed by any object during its operation. Due to this aspect, it is recommended to mount the safety scanner in areas of interest where its detection area is not obstructed.

The safety barriers, also known as light curtains, consist of an emitter and a receiver. They must be perfectly mechanically aligned to send the electrical signals on two channels. They are powered at an electrical voltage of 24 V DC, which is also the working voltage. When the signal between the transmitter and the receiver is interrupted, the safety barriers will interrupt the signals on the two 24 V DC channels, until the signal between the transmitter and the receiver is no longer obstructed. These will be connected to the signal distribution terminals that will transmit the signal further to the safety PLC. By interrupting the signals, they will achieve the safety stop of the collaborative robot. When the signals from the two channels will be sent again by the safety barriers, the collaborative robot will automatically restart from the remaining point. These are much lower in terms of purchase cost compared to perimeter scanners, but their functionality is also much more limited.

The emergency and reset buttons must be positioned within sight and reach of the operator or worker. If the application needs to be stopped urgently, by pressing the emergency button by the operator, the emergency button will disconnect the NC contacts thus interrupting the 24 V DC signals from the two channels that reach the safety PLC. The safety PLC will, in the future, disconnect the signals from the two channels that will reach the collaborative robots, these being stopped in an emergency. If you want to restart the application, it is also recommended to have a button to reset the safety system. By pressing it, a signal is sent on a single channel of 24 V DC through a pulse to the safety PLC. The time the button maintains the electrical signal is equivalent to the time the button remains pressed by the operator. This is a return button, therefore, after the operator stops pressing the button, the signal will be stopped. When the safety PLC receives the signal from the reset button, it will reset the safety system and the application can be restarted.

NC is an abbreviation for normally closed or normally closed. Buttons with normally closed contacts keep the circuit closed until the button is pressed.

NO – abbreviation for normally open or normally open. Buttons with normally open contacts keep the circuit open until the button is pressed.

The auxiliary safety systems communicate permanently on two channels with collaborative robots. Two channels will stop the emergency circuit of the collaborative robots and two channels will stop the safety circuit of the robot. After stopping the emergency circuit of the collaborative robots, they will have to be restarted and referenced because the tension on their joints is off. In this situation, the application will have to start from the beginning. The emergency circuit will be disconnected only through the emergency button and reset through the reset button. In case of shutdown of the safety circuit, the collaborative robot will go on pause, the tension on the joints of the robot being maintained. When the safety circuit is re-energized, the collaborative robot will restart from the same point. The safety circuit will be disconnected only through the safety perimeter scanners and the safety barriers.

## 4. ELECTRICAL INTERFACE OF THE COLLABORATIVE ROBOTS FROM UR

The safety systems must be dynamically designed for the collaboration between man and robot [8].

Collaborative robots are designed with certain electrical inputs and outputs, both digital and analogue. They can be used to communicate with the surrounding equipment or the clamping devices used by it [9]. Depending on the electrical inputs, certain conditions can be programmed that the collaborative robot will follow, and also through the electrical outputs, it will be able to command certain equipment or devices.

The study of this aspect was carried out on a collaborative robot from Universal Robots type UR10. It is provided with electrical inputs and outputs in the connector for the tool, as well as in the control box. In the connector for the tool, the following can be distinguished:

- 2 digital electrical inputs;
- 2 digital electrical outputs;
- 2 analogue inputs.

24 V DC power supply that can be used to power the tool used by the collaborative robot.

In the control box it is provided with the:

- 16 digital electrical inputs, 8 of which are configurable;
- 16 digital electrical outputs, 8 of which are configurable;

- 2 analogue inputs;
- 2 analogue outputs.

The operating voltage is 24 V DC, as in the case of auxiliary safety devices. To have the same electrical potential, an electrical wire called common will be used that will be connected to 0 V DC between the collaborative robot and the surrounding equipment. Also, the signal that the collaborative robot can send through the digital outputs is at 24 V DC.

Electrical digital inputs can be active or inactive. When they are active, it means that they receive a 24 V DC signal, and when the signal is interrupted, it will be deactivated.

The electrical digital outputs can be activated or deactivated from the robot program depending on the need. These activations and deactivations can be activated automatically from the collaborative robot program.

The collaborative robot can also decode analogue values. It can read the current, expressed in mA, as well as the voltage, expressed in V. The analogue value to be interpreted is set by the programmer.

The values it can diagnose for analogue inputs are:

- For current between 4 and 20 mA;
- For voltage between 0 and 10 V.

Also, the collaborative robot can use analogue outputs to transmit the signals. The values it can send can be either current or voltage. The limits of the analogue outputs are the same as those of the analogue inputs used.

These electrical inputs and outputs can be found in the control box, where the electrical signals will be connected. Each electrical input and output is connected fixed through a screw existing in the connectors. Also, the correspondence of each signal can be seen on the command tablet of the collaborative robot in the I/O menu of the collaborative robot. This aspect can be observed in figure 3.

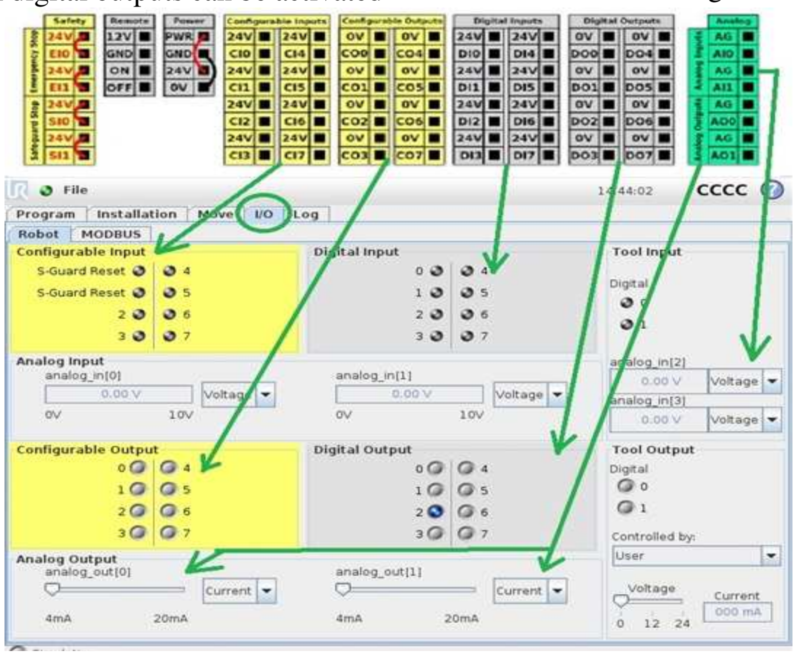


**Fig. 3.** Correspondence between the electrical signals connected in the connectors and their control on the command tablet of the collaborative robot

From the existing I/O menu on the collaborative robot tablet it is possible:

- Manually actuate the digital electrical outputs;
- Visually check the digital inputs;
- Manually actuate the analogue electrical outputs;
- Visually check the analogue inputs.

The digital inputs will light up on the tablet interface when the collaborative robot receives a signal from a piece of equipment. Also, when the collaborative robot sends a digital command through the output, they will be lit on the tablet interface.

## 5. CONCLUSIONS

The scientific work is focused on safety solutions that can be used to create a safety system.

In chapter 2, the components of the auxiliary safety system used in the integration of collaborative robots were presented. The components that make up the safety system were highlighted: perimeter scanning, safety barriers, safety PLC and safety output relays.

Next, the principle of electrical operation was presented for each component element that is part of the safety system of an application with collaborative robots. The possibility of integrating the entire control system into an electrical panel was also exemplified.

Next, the electrical interface of the collaborative robots from Universal Robots was highlighted and the correlation between it and the software running on the collaborative robot was presented.

The scientific work was developed to provide a viable scientific safety solution in terms of protecting human safety and health following the implementation of collaborative robots on production flows.

The authors consider the fact that human health and life must always have priority.

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## IMPLEMENTAREA SISTEMELOR DE SIGURANȚĂ ÎN APLICAȚII CU ROBOȚI COLABORATIVI


***Rezumat:*** *In prezent, roboti colaborativi reprezinta o alternativa viabila pentru a imbunatati eficienta, eficacitatea si calitatea unui proces de fabricatie de serie. Acestia pot fi regasiti in tot mai multe fluxuri de fabricatie atat in industria automotive cat si in alte industri. Roboti colaborativi pot fi integrati si utilizati in numeroase procese de fabricatie. Desi roboti colaborativi au fost creati pentru a imparti mediul de lucru cu operatorul, exista aplicatii in care roboti colaborativi opereaza uneltele la o viteza ridicata in fluxul de fabricatie. Datorita acestui aspect a fost necesara gandirea si implementarea unui sistem de siguranta care va proteja suplimentar omul in momentul interactiunii cu robotul colaborativ. Lucrarea stiintifica prezinta un sistem de siguranta implementabil in aplicatiile cu roboti colaborativi.*



***Keywords:*** *robot colaborativ, auto, siguranță, automatizare, sisteme, soluții electrice.*



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