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INTEGRATED SAFETY ARCHITECTURE FOR COLLABORATIVE ROBOTICS USING A UR3 ROBOT, SICK S3000 SCANNER AND SIEMENS S7-1200 PLC

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Abstract: *This article presents a detailed collaborative robotic architecture that integrates a UR3 robot, a Sick S3000 laser safety scanner and a Siemens S7-1200 PLC into a unified mechatronic cell designed for safe human-robot interaction. The scanner was configured with a three-field safety structure-warning, protective stop and emergency stop-allowing the robot to dynamically adjust its behavior based on the operator's proximity. The PLC supervises a pneumatic assembly module and performs deterministic synchronization with the robot using a digital handshake signal. Mechanical supports and integration components were designed in Catia V5 to ensure structural coherence and accessibility of the equipment. Experimental validation demonstrates stable performance, predictable safety responses and smooth coordination between robotic and pneumatic processes. The proposed system provides an effective example of how industrial components can be integrated into a compact collaborative workstation suitable for both educational and industrial settings.*

Key words: Safety scanner; Industrial automation; UR3 robot; Sick S3000; Programmable Logic Controller; Pneumatic actuation; Human–robot interaction; Mechatronic systems; Safety architecture.

1. INTRODUCTION

Collaborative robotics represents a strategic direction in the development of modern production systems, contributing to increased flexibility and adaptability of industrial manufacturing lines[1]. The integration of robots in close proximity to human operators, without extensive physical barriers, requires advanced perception and control mechanisms capable of managing the dynamic variations of the working environment[2]. The selection and optimal configuration of robotic equipment play a crucial role in ensuring performance and safety within collaborative processes, particularly in flexible manufacturing environments[3]. In innovative technological applications, such as robot-assisted incremental forming, the implementation of adaptive control becomes necessary to guarantee both process accuracy and operational safety[4]. Functional safety constitutes a fundamental element in the design of collaborative cells, considering the direct proximity between the operator and the robot. Industrial laser scanners are frequently employed for perimeter monitoring and collision prevention in autonomous and collaborative applications[5]. International standards such as ISO 10218 and ISO/TS 15066 provide the reference framework for limiting biomechanical risks and defining robot behavior in relation to human presence[6]. A recent trend in the automation industry involves the integration of the digital twin concept and cyber–physical platforms for real-time monitoring and optimization of robotic systems[7]. In this context, integrated collaborative architectures are becoming a major area of interest for research and industrial applications.

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2. STATE OF THE ART IN COLLABORATIVE ROBOTIC ARCHITECTURES

The specialized literature highlights a wide range of approaches in the field of collaborative robotics, including the optimization of manipulator kinematics through fuzzy methods [2] and the optimal selection of industrial robots based on performance criteria [3]. In advanced industrial processes, the use of robots for incremental forming and assisted machining has been documented in recent studies, confirming the necessity for flexible and safe architectures [4], [8]. Perimeter monitoring using laser scanners represents a well-established solution in AGV implementations and collaborative industrial applications, contributing to collision prevention and increased operational safety [5]. The integration of digital twin technologies enables real-time analysis of complex systems and the optimization of their operation [7]. The role of industrial PLCs in deterministic control and synchronization of mechatronic subsystems is emphasized in numerous implementations, including applications employing Simatic S7-1200 controllers for distributed monitoring and control [9]. The development of communication between PLCs and embedded systems confirms the potential for extending robotic system functionality through industrial Ethernet-based protocols [10],[11],[12].

3. MATERIALS AND METHODS

The experimental architecture proposed in this work integrates a UR3 collaborative robot, a Sick S3000 safety laser scanner, and a Siemens S7-1200 PLC, configured within a mechatronic structure designed for pneumatic handling and assembly. The use of industrial PLCs in such applications confirms their robustness and reliability in controlling distributed processes. To support the development of the system, a CAD model of the collaborative cell was created, as illustrated in Figure 1, showing the physical arrangement of the main experimental components. The UR3 robot is positioned on the right side of the structure, with free access to the manipulation area, while the MecLab module, equipped with pneumatic elements and sensors, is located on the left side. The Sick S3000 scanner is mounted at the front, oriented to monitor the entire operator access zone and to enable the configuration of safety fields. This representation contributes to the conceptual validation of the architecture and to the optimization of component placement prior to physical implementation.

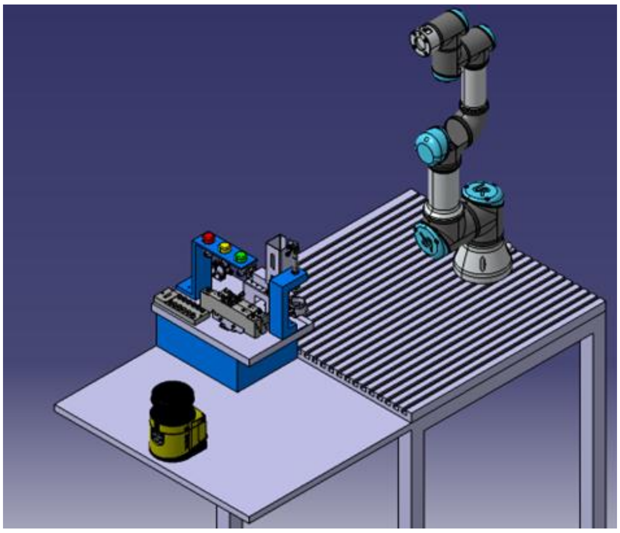

Figure 1. CAD model of the UR3–MecLab–S3000 collaborative cell.

The interconnection between the robot and the PLC was achieved through a digital handshake mechanism, a method commonly used in modern industrial implementations to synchronize mechatronic subsystems [14]. This communication structure enables deterministic control of pneumatic actuators and robot movements, helping to prevent logical conflicts and increase operational safety. The experimental methodology included the configuration of detection fields in the Sick CDS software, programming the PLC in LAD language, and developing the UR3 robot logic, with the objective of evaluating system behavior under real operating conditions.

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Vol. 77 2025

4. SYSTEM ARCHITECTURE

The collaborative UR3–Sick S3000–S7-1200 system architecture was designed to ensure a clear separation between the safety layer and the control layer, an essential principle in modern collaborative implementations aimed at reducing reaction times and guaranteeing immediate shutdown in critical situations. The hardware structure includes direct connections between the safety scanner and the robot, as well as a logical integration through the Siemens S7-1200 PLC, which manages pneumatic actuation and sensor monitoring. The system interconnection diagram is shown in Figure 2. It highlights the routing of critical signals, particularly the R4 line originating from the Sick S3000 scanner, which is transmitted directly to the UR3 robot safety input and to the relay interface, bypassing PLC software processing. This approach enables emergency stop activation with minimal delay, a fundamental requirement for operator protection in collaborative applications. Within the relay interface module, electrical adaptation circuits are implemented to ensure signal level compatibility and galvanic isolation between subsystems. The PLC receives only auxiliary signals and controls the pneumatic actuators, allowing the system to maintain functional operation under safe conditions until a critical event occurs.

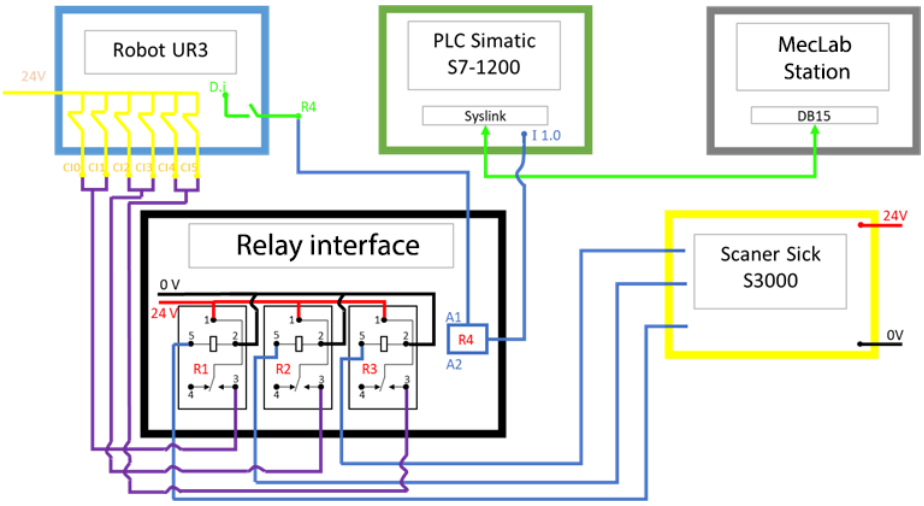

Figure 2. Electrical interconnection diagram between the UR3 robot, Siemens S7-1200 PLC, Sick S3000 scanner, and the MecLab station.

This hybrid architecture enables immediate shutdown through a dedicated hardware circuit (R4 line), controlled stopping through the PLC–robot logic, and speed reduction based on the active safety field, while maintaining operational continuity in non-critical situations. Through this multi-layer structure, the system successfully balances user protection with process efficiency, preserving station functionality without unnecessary interruptions.

5. SAFETY CONFIGURATION AND STANDARDS

The implementation of safety within the collaborative cell was carried out in accordance with the requirements of ISO 10218 and ISO/TS 15066 standards, which define the functional structure of protection zones and the biomechanical limits permitted during human–robot interaction. The Sick S3000 laser scanner was configured using the dedicated Sick CDS software, allowing the definition of differentiated detection fields and the assignment of specific system responses to each zone. Figure 3a. presents the configuration of the scanner inputs and outputs, where the mapping of warning and stop signals to the safe output channels can be observed. This step ensures the correct transmission of safety information to the relay interface and subsequently to the PLC and the robot, forming the functional basis of the safety architecture.

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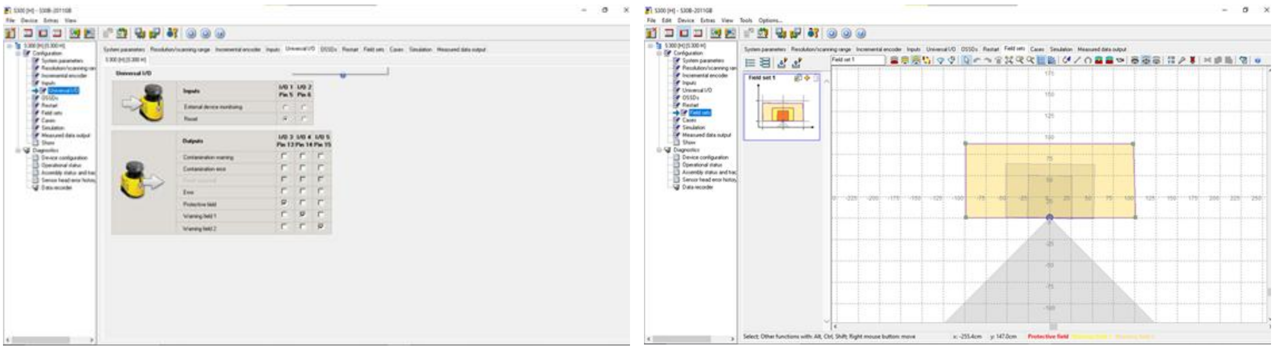
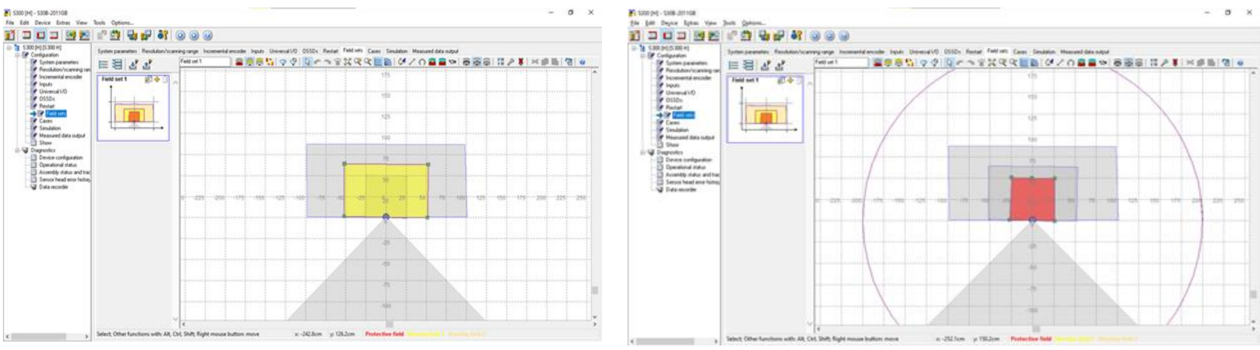


a. Configuration of the scanner inputs and outputs. **b. Definition of the outer warning field**
Figure 3. Configuration of Sick S3000 scanner using the dedicated Sick CDS software

Figure 3b. illustrates the outer warning field, represented in yellow. Activation of this zone triggers a gradual reduction in robot speed, contributing to limiting the kinetic energy transferred in the event of unintended interaction between the robot and the operator. This reaction level enables process continuity without compromising user safety.

Figure 4a. shows the intermediate field, where the monitored area activates a controlled stop of the robot and deactivates the pneumatic actuators without initiating a full system reset. This function is essential for reducing downtime and maintaining an efficient operational workflow. Figure 4b. depicts the inner field, represented in red, associated with the activation of the emergency stop. The signal generated in this area is transmitted directly through the dedicated hardware circuit to the robot and the PLC, bypassing software processing and significantly reducing system reaction time—a critical aspect in collaborative applications [10].



a. Intermediate field **b. Inner field**
Figure 4. Configuration Field of Sick S3000 scanner using the dedicated Sick CDS software

Figure 5 presents the real-time monitoring output, highlighting the shape of the protected area detected by the scanner and the trajectory of identified objects. This visualization confirms the correct functioning of the system and the scanner's ability to detect intrusions dynamically, adapting system reactions based on operator position.

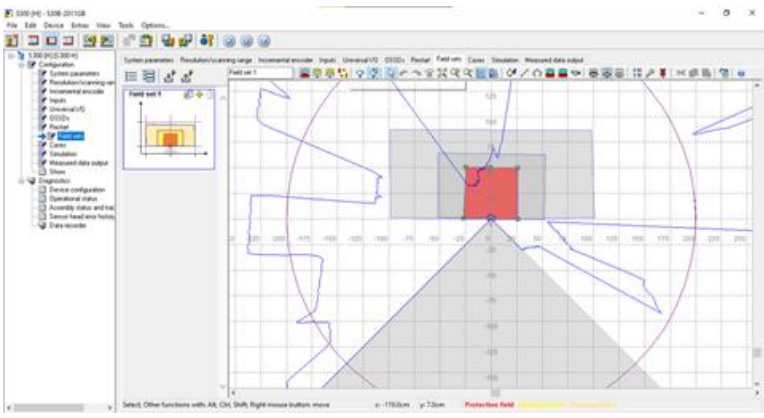


Figure 5. Real-time perimeter detection visualization in Sick CDS.

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Vol. 77 2025

6. EXPERIMENTAL IMPLEMENTATION AND VALIDATION

To validate the functional performance of the developed architecture, a collaborative application was implemented in which the UR3 robot performs handling and assembly operations on the MecLab workstation, coordinated through the Siemens S7-1200 PLC. The main objective of the application was to demonstrate the synchronization between the robot–PLC–safety subsystems and to evaluate the system behavior under real operating conditions. The process begins with the robot positioning itself in the component pickup area, followed by transferring the component to the MecLab workstation, as illustrated in Figure 6. At this stage, correct communication between the robot and the PLC can be observed, with the pneumatic actuators being activated only after the robot′s position is confirmed, preventing unintended activations. After pickup, the robot positions the component into the assembly fixture, where the pneumatic mechanism secures it, as demonstrated in Figure 7. The synchronization between the robot motion and pneumatic activation confirms the correct implementation of the handshake logic, ensuring process repeatability and preventing collisions with system elements.

a. Initial positioning at the MecLab workstation **b. Component pickup**

Figure 6. Application of the UR3 robot in component handling

a. Insertion of the component into the fixture **b. Pneumatic fastening**

Figure 7. Execution of the assembly operation

7. CONCLUSIONS

The study presented the development and implementation of an integrated collaborative architecture based on the UR3 robot, the Sick S3000 safety laser scanner, and the Siemens S7-1200 PLC, intended for pneumatic handling and assembly scenarios. The multi-level safety structure, built on differentiated detection fields, enabled an optimal balance between operator protection and process continuity, activating a full system shutdown only in critical situations. Experimental results demonstrated a reduced reaction time to safety events, accurate synchronization between the robot and the PLC, high repeatability of handling cycles, and a stable and functional hardware–software integration, validating the feasibility of using collaborative systems in both educational and industrial applications and confirming their potential to enhance process flexibility and operational safety. Future work will focus on integrating a digital twin model for predictive monitoring, implementing a force-interaction monitoring system to further increase safety levels, and extending communication capabilities through advanced industrial protocols such as OPC UA to improve interoperability. Overall, the results contribute to strengthening collaborative approaches in modern production environments, demonstrating the viability of an integrated robot–safety–automation solution.

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