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# *Deep Learning for PLC-Based Industrial Robots*

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***Abstract.*** With the deepening of Industry 4.0 and the intelligent transformation of manufacturing, industrial robots are becoming the core equipment of automated production. PLCs have been deeply coupled and integrated with industrial robots due to their high reliability and strong anti-interference ability, and the control performance has been greatly improved. The aim of this paper is to study industrial robotic systems taking PLCs as the main technology, and to study the basic integrated technologies of industrial robots and PLCs, the coupling of PLCs and industrial robots, the technology integration of industrial robots, and integrated technologies. Additionally, I will describe the problems of dependency on the high-end core technology imports, the high integration of industrial robots and PLCs, the high technology integration, the high application, and the integration barriers of the technology, and high application barriers of the integrated technology. This study also provides some suggestions on the integration of industrial robots and PLCs in the future. In the study, I have identified various issues in the field of integrated technologies and the dependence on PLCs, as well as the high application barriers in the study, and have provided some basic references for the technology in the study area. The study focuses on the PLCs, the integrated technologies, and the high level of the industrial development. In addition, the study fills the gap in the study area and provides some references for the high-quality development of the integrated technologies in the PLCs and the small and medium enterprises technologies.

***Keywords:*** programmable logic controller, industrial robots, deep learning

## 1. Introduction

The intelligent transformation of manufacturing implemented with the National Development plan has placed Smart Manufacturing as one of the key elements to improve the core competitiveness of the National Manufacturing Industries and the achievement of Quality Development. The Smart Manufacturing characterizes the flexibility and intelligence of manufacturing systems. In the Manufacturing Industries Automation systems, the Industrial Robots have a significant role and have a great impact in alleviating the shortage of workforce, and enhancing the Quality and Efficiency of Production. The Automation systems and Industrial Robots application level is a benchmark for Production Automation degree and the Industrial competitiveness of the Company and the country. The Industrial Control Systems diagram Schemes and of the elements of the systems describes the functions of the Programmable Logic Controller (PLC) as Control systems core devices, which have

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a proper balance of reliability and the ability to withstand harsh environments and flexible for programming, as well the PLCs in the Control Systems, show the Automation Systems Gradation systems PLCs in Control Automation Systems, show systems high-degree Automation. The merging of PLC and Industrial Robots systems, not only integrates the features of both systems, but also removes the walls, creates a possibility of the first step for the Automation Systems, new economically feasible solution for Tier Small and Medium Enterprises Automation Systems.

Poland and many other countries have made new developments on the integration of PLCs with industrial robots. For the other counties the systems and their integration with all the advanced control technologies and algorithms are well developed. While on the other hand Polish scientists have developed integration of systems with application scenarios. Nonetheless, the existing research has limited scope. Countries of the European Union and especially the research conducted in Poland, has a significant dependence on foreign high-end PLC technologies. Also noticeable is the lack of research in small and medium enterprises, not to mention the absence of such in other countries, especially Poland and the countries of the European Union. There is no in-depth research in the field of small and medium enterprises, there is no research in the field of theoretical foundations and there are no valid guidelines and recommendations on how to construct PLCs and robot systems automated and integrated systems. Most of the existing research is focused on large enterprises and large systems, there are no integrated systems industrial automation and control systems.

Thus, the study analyzes PLCs and automation, and integrated systems techniques. The study has been focused to be able to identify gaps in the existing literature and research, issues, and problems, and also to be focused on small and medium enterprises. The expected aim of this research is to be able to document the available theoretical foundations in the existing literature, integrated systems, and other related fields, and to propose and outline the existing problems, gaps and theoretical foundations in control systems. Systems in a way that will help small and medium enterprises to implement and develop systems that will increase the automation and provide the integrated systems with the PLCs.

## 2. Current status of PLC-based industrial robot technology development

### 2.1. The foundation of PLC and industrial robot integration

The merger of industrial robots and Programmable Logic Controllers (PLC) technology offers remarkable importance in terms of technological feasibility. The two have remarkable compatibility in control logic and communication standards. Prior studies have validated that industrial robot control systems based on PLCs provide control reliability and stable execution of instructions, thus offering a strong technical foundation in support of integrated applications of PLCs and industrial robots. There are clear benefits from this merger, such as lowering cost of industrial robot control systems, improvement system stability and flexibility to operate. It also makes the programming and maintenance easier, supporting the integrated control of robots and other equipment on the production line, in particular, the automation of small and medium enterprises (SMEs) [1].

The integration of PLCs with industrial robots generally follows two models. In the first model, the PLC assumes the role of primary controller and immediate manager of the robot. This model functions best in small to medium-sized production lines with basic operational structures. In this case, the PLC handles everything from receiving sensor signals to executing control instructions, and driving the robot through specified actions. Because of its relatively low cost and ease of operation, this model is attractive. The second model involves collaboration of the PLC with a robot

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controller in a role that could be described as coordinating. This model is best for complex production lines and multiple robot collaborations. Here, the PLC can serve in the upper-level coordinating role while the execution of robots is handled by a ROS 2 based framework. This approach improves the efficiency and flexibility of coordinated industrial robot manipulation [2]. The second model is the manipulation model that is frequently employed for tasks that require utmost precision. The integration of PLC with industrial robots has undergone changes in response to advancements in technology and industrial demand. In the first iterations, control of PLCs and robot programming were carried out separately and independently of each other. The most recent advancements have facilitated a means for external PLCs to send dynamic robotics control sequences (DSR) to the robots. This is exemplified by KUKA's Automaton. The developments ushered in a new framework for PLCs to control robots and other systems in a workshop. This technology consists of two distinct components.

The first is a server program on the robot controller that is meant to communicate and receive commands from the external PLC. The second one is a coordinator program on the PLC itself. With the help of the robot vendor's PLC library, all the commands and parameters for the robot are encapsulated into the correct format, then sent to the server using fieldbus, UDP, or TCP/IP. The server processes the commands in the data packets, executes the commands, and sends back some parameters and status updates to the PLC. This way, the code developed in the PLC can control robotic tasks directly [3]. This method, at first sight, seems to duplicate the functionality of the previous control model, but in reality, it has a significant benefit that it allows much more accurate control over how robotic tasks are executed. The difference is significant and can be seen in Figure 1.

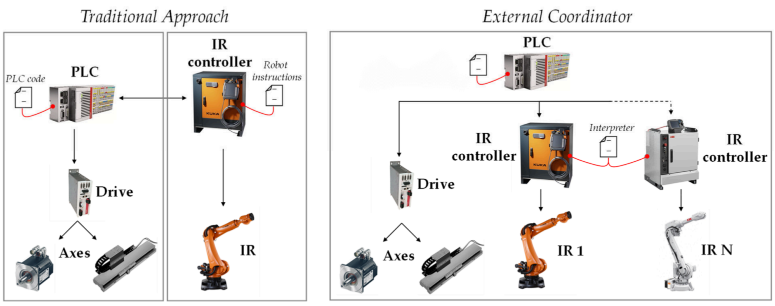


Figure 1. Traditional framework with multiple parallel controllers vs. approach adopting a centralized PLC coordinator to control the production plant [3]

## 2.2. Applications of PLC technology and its integration with industrial robots

In real-world manufacturing, Programmable Logic Controllers (PLCs) and industrial robots are mainly integrated in five main control scenarios. First, sequential control. PLCs have the capability to instruct robots accurately to execute continuous operations like gripping, carrying, assembling, welding, and spraying in preset orders. This will guarantee standardized work processes, the time of execution, and avoidance of conflicts of motion, which increases continuity of operations. Second, logic control of switching and safety. PLCs control start/stop operation, emergency stops, limit protection, and gripper operation using discrete control signals. They can track the condition of safety doors and collision indicators in real-time, which activates protective devices as soon as there are abnormal conditions, which enhances the safety of robotic operations many times over. Third, closed-loop accuracy control. Sensors which monitor position, speed and torque provide real-time feedback to the PLCs comparing the sensor readings to pre-set parameters and automatically fine-

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tuning the outputs. This enables extremely fine robot positioning and path control, which is suitable to very demanding tasks like precision machining and fine assembly. Fourth, servo control and motion. PLCs act upon servo and stepper types of motors directly to allow multi-axis coordination and more intricate route calculations. This gives the much-needed control of the flexible movement of robots which is vital in the current automated production scenarios. Fifth, automatic switching and redundancy control of systems. PLCs can detect the status of robots and equipment in real time and automatically start backup mechanisms or change the operation routes during faults or workstation dynamism to ensure the stability and continuous operation of production lines [2].

With the ongoing development of PLC technology to be more intelligent and flexible, and the industrial sector demanding smarter and more connected automation of industrial robots, the convergence of PLC systems with machine learning and adaptive algorithms is gaining pace. It is anticipated that this trend will allow robots to autonomously tune control parameters, optimize task trajectories, and perfect decision making based on the dynamically operating conditions. Through this, robots will be in a better position to handle complex, variable and unstructured production environments. Meanwhile, the growing use of PLC technology in electrical automation control is pushing it to become increasingly smarter, integrate its various subsystems more effectively, and coordinate their actions more effectively to offer more robust technical support to the stable, efficient, and continuous functioning of automated production systems [4]. Moreover, openness and interoperability have made advancements that are slowly tearing down communication obstacles between robots and controllers manufactured by other manufacturers. This not only makes the system integration less expensive and less complicated but also makes the production line design and reconfiguring much more flexible. Practically, it is easier to unite heterogeneous devices in the same control system, which is beneficial in reducing commissioning time and enhancing the effectiveness of further maintenance and upgrades. Meanwhile, the design concepts of modular and standardization allow PLC based robot systems to be more deployed, expanded and customized, so that they can be used in greater variety of industrial applications. These designs also accommodate the compatibility with various types of robots such as articulated robots, collaborative robots as well as mobile robots which also enlarge the range of application of PLC based automation systems [5].

In general, the high interconnection of PLCs and industrial robots has already enhanced the precision of control, productivity, and safety of the system. More significantly, it is establishing a more solid technological base to the coordinated, versatile, and smart working of automated production lines. As the intelligent control, interconnection ability, and compatibility of the system continue to improve, the PLC based industrial robot system will likely have greater significance in the future progress of the modern manufacturing process.

### 2.3. Global and domestic development trends

In general, there are advancements in globally PLC-based industrial robot technologies and tending more towards real time technologies, intelligent technologies, and more connected technologies. Some newly developed technologies, like soft PLCs, industrial real time buses, etc., have recently been used more and more in industrial control systems, and have substantially improved control precision, response time, and overall efficiency in the operational systems of those control systems. Concurrently, PLC-based robot systems have been used in a wider range of application areas. These used to be primarily rote and predictable applications, like automotive manufacturing and electronics assembly. Now, these robot systems are used in aerospace, renewable energy, logistics, and a multitude of new industries. This increasing application area is providing a plethora of successful engineering examples and further substantiating the value of the integration of PLCs and

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industrial robots. One example is the design of a PLC-based industrial robot loading and unloading control system, which effectively resolves the issues of limited efficiency and precision of the traditional manual operations and fully supports the further development of industrial automation, while the robotic functions remained unchanged. The experimental results substantiate the claim wherein the system was able to shorten TCP trajectory convergence time by 23.40%, gripper open and close response time was reduced by 40.00%, robot motion conflict rate was decreased by 57.10%, visual localization average error was reduced by 38.90%, and the system improved grasping success rate by 7.70% in comparison to traditional systems [6].

Siemens, Mitsubishi Electric, and Beckhoff integrate advanced technologies to construct extensive PLC product portfolios and achieve integrated technologies with industrial robots and comprehensive industrial ecosystems. China's industrial robots are being rapidly deployed with high installation volume and robot density globally. Integrated domestic PLC and robot solutions are replacing imports in mid and low-end markets. The high-end applications gap aligned with global standards is diminishing and localization of primary components is accelerating. Innovance and Estun have introduced PLC products, which is a positive development for Chinese industrial automation's self-reliance and innovation. Technological application scenarios are also rapidly expanding, with some research. For example, studies based on provincial data in China have quantified and confirmed strong momentum of industrial robot development. In Du and Lin's research, they claim \"industrial robot application in China is significantly associated with regional total factor productivity, and exhibit spatial effects\", thus elucidating increased industrial upgrading and regional economic transformation [7].

## 3. Key issues and development prospects

### 3.1. Existing key issues

Innovations with PLC-based industrial robots continue to be impeded by technological and industrial-specific challenges. Technologically and in terms of application, the sector continues to rely on imports. Advanced PLC chips and proprietary dominant core algorithms and control technologies are all held by foreign companies, leaving local firms disadvantaged. There is little adaptability for control of complex scenarios. Stability in control of high precision, highly flexible, and extreme environment operations is lacking. High end sectors like aerospace and precision manufacturing have highly articulated control demands which remain unmet. For small and medium-sized enterprises, the cost of control of PLC + robots is high, as is the need to have specially trained staff for operation and maintenance, making the technology highly rigid. Role of professional manpower is also critical as the PLC programming and industrial robots converge. They are needed to break the development scales of the industry. From an industry perspective, the absence of a unifying standard and testing technology for industrial components reinforces fragmentation regarding the interfaces and communication protocols between PLCs and robots across various companies. Problems related to low component precision adversely affect the compatibility of devices and, ultimately, the quality of collaborative tasks. Furthermore, recent analyses demonstrate that the robotics innovation ecosystem is moving from top-tier universities to industrial companies and governmental labs, highlighting the need for more robust industry-driven collaboration and practical innovation initiatives for the robotics innovation ecosystem to thrive [8].

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### 3.2. Development prospects and outlook for PLC-based industrial robots

As the intelligent manufacturing plan progresses unabated, PLC-based industrial robots, with their distinct benefits, have a wide growth opportunity in future. Technologically, the PLCs will keep on advancing towards being more intelligent, integrated and smaller. Soft PLCs will be further integrated with technologies (AI, machine vision, and edge computing) to allow industrial robots to make autonomous decisions, operate and maintain intelligently, and control accurately, as depicted in Figure 2. This will eventually destroy the monopoly of high-end technologies and increase the degree of independent control of core technologies.

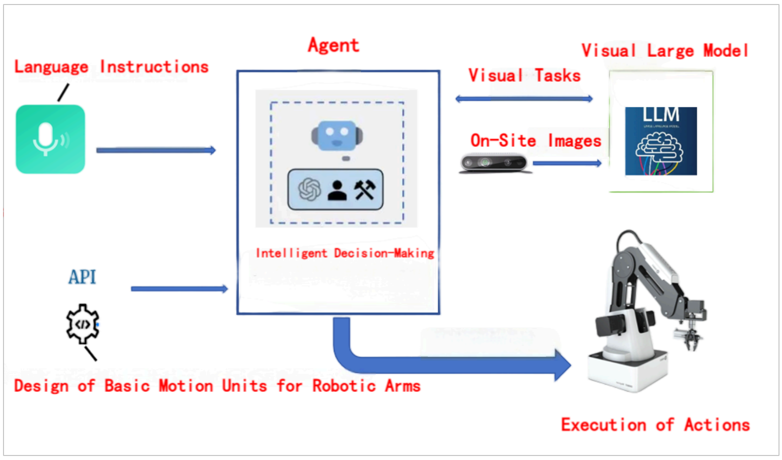


Figure 2. Multi-modal large model AI control system for industrial robots [9]

Collaboration control technology concerning PLCs and industrial robots will continue to evolve and enhance both safety and efficiency in multi-robot coordination and human-robot collaboration. There has been testing of the cycle time that possibly latency can be achieved with wireless communication technology; with 4G supporting cycle time that is greater than 30 milliseconds while WLAN and 5G non-standalone (NSA) networks can achieve cycle time of 20 milliseconds. The bigger cycle time robots can move slower. There are also benchmark studies comparing different wireless communication systems of which WLAN reported 1.77 milliseconds, 4G 23.88 milliseconds, and 5G NSA 6.56 milliseconds latency [10]. It can be argued that 5G technology will also be able to respond quickly. The combination of 5G and PLCs based industrial robots will enhance the operational capabilities of industrial robots.

## 4. Conclusion

This research uses a systematic approach to studying PLC based industrial robots. In doing so, this research showcases the exceptional reliability and programmability of PLCs and how they integrate into various components of industrial robotics such as sequential control, closed loop precision control and motion control servo. PLCs serve as the basis in the development of industrial robotics and enable industrial robots to work with a high level of precision, efficiency, and safety. In the global context, related technologies such as PLCs are evolving to provide even greater real time performance, smart technologies, and enhanced connectivity. International markets have a considerable lead in most advanced technologies. In the local economy, there are major advancements in the industry's reliance on mass production and the self-sufficiency of mid and lower tiers products. Specifically, there have been rapid advancements in the self-sufficiency of the core components of PLCs. Despite significant advancements, there are challenges such as the majority of essential components, high level PLC chips and core algorithms, being reliant on imports. Other identified challenges include a lack of industry standards, rigid design for complex situations, high cost of applications, and inadequate qualified workers. All these challenges have impeded the rapid advancement of the industry.

This research provides one of the first theoretical perspectives on the integration of PLCs with industrial robotics with respect to small and medium sized enterprises. The results of the research provide a wide range of options and flexibility for small and medium sized enterprises to improve their operational efficiency and quality of their products. The research provides rational solutions for enterprises as they get in to industrial automation and begin to implement smart manufacturing. All these factors have helped improve the competitiveness of the manufacturing industry in general in the local economy.

In the OEM market PLC-based industrial robots, the leading-edge application will be PLCs bridging the gap between robotics and OEMs. PLCs will provide the technology required for significant new advancements in both robotics and OEM. These advancements will consist of high integration of PLCs with Artificial Intelligence (AI), 5G and Edge Technology for autonomous decision making and robotic remote intelligent operation and maintenance. In addition to the traditional sectors, new applications will include high-end scenarios like Aerospace and Renewable Energy. Lowering application barriers will fully satisfy the automation needs of small and medium-sized enterprises (SMEs). Accelerating industry standardization, collaboration between industry and academia, research focus, and comprehensive education will increase the competitiveness of domestic PLC brands. Automation will empower Smarter Manufacturing. PLCs will provide the technology needed to achieve China's goals to be the world's manufacturing power.

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