

PLC-Controlled Coordination of Multi-Arm Robotics Without Cooperative Devices for Task Execution

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Abstract

The integration of multiple robotic arms for collaborative tasks often involves complex cooperative motion functions. This study introduces a research framework aimed at orchestrating multi-robotic arms for non-cooperative task execution in a slot-car transfer system, controlled solely by a Programmable Logic Controller (PLC). Unlike traditional approaches reliant on synchronized controllers, this framework excludes cooperative motion functions, focusing on two robot arms with six and four degrees of freedom. The PLC governs and coordinates the sequential movements of both arms, utilizing readily available laboratory and commercial components. To ensure compatibility and synchronization, a rigorous analysis of component specifications was conducted, addressing I/O signal mapping, voltage matching, and mechanical adaptation. A PLC-based control system manages coordination through pre-programmed delays, sensor feedback loops, and independent motion trajectories, ensuring precise and repeatable execution. Custom platform holders were developed to facilitate stable grasping and transfer of the slot car. This study specifically outlines the process of transferring a slot car across two platform tracks using Selective-Compliance Assembly Robot Arm (SCARA) and Articulated Robot Arm. Experimental results validate the feasibility and effectiveness of the proposed PLC-controlled coordination method, demonstrating that different robot arms can collaborate efficiently without requiring cooperative motion functions. The findings highlight a scalable and adaptable approach for integrating heterogeneous robotic systems in real-world industrial applications.

1. Introduction

A robotic arm is a mechanical assembly that emulates the anatomical structure of the human arm, comprising rigid links engineered for robustness and endowed with articulation capabilities enabling rotational or translational movement at joint interfaces [1]. The robot's base firmly secures one extremity, providing stability for both its intrinsic mass and any supplementary loads, while the opposite end remains unbounded, serving as the locus for tool attachment and task execution. Throughout task execution, the robotic arm's joints and links engage in coordinated relative motion, traversing the entirety of the workspace to access every point, including the farthest and nearest secure positions attainable by the end-effectors [2]. In practical use, robot arms undergo ongoing enhancements to achieve heightened performance, facilitated by their multifunctional manipulators tailored for the handling of diverse materials, specialized end-effectors, or machined components. These manipulators operate programmatically, enabling the execution of a myriad of tasks. The impact of robotic arms

extends across numerous domains, revolutionizing techniques and management practices to ensure consistency and precision in task execution. Their application spans various industries, encompassing activities such as design, manufacturing, inspection, and assembly, as well as specialized research endeavors in underwater, space, and planetary surface exploration [3]. Currently, the collaboration of two robot arms, particularly for task optimization, is widely practiced, aiming to enhance effectiveness and efficiency. Typically, such cooperative actions involve identical robot arms, leveraging their congruent specifications and software interfaces.

In the realms of mechatronics and robotics, recent advancements have facilitated the establishment of collaboration between two robot arms. For instance, Justin [4], a two-armed robot with 7 degrees of freedom, employs a sophisticated joint-level control and complex planning algorithm to undertake diverse tasks and services within human environments. Another example is the Robots Layout Slot-car Track by DENSO Robotics [5], which involves the collaboration of identical robots possessing 6 degrees of freedom. These robots are controlled using the binary controller access protocol (b-CAP), enabling synchronized motion during real-time planning. Additionally, Workerbot [6], a dual-armed robot with 7 degrees of freedom, utilizes the dual-arm robotic language (DA-RL) to execute manipulative actions within its developed control system. Despite differences in their manipulation systems, these robots share a common objective: the execution of designated tasks. The cooperative motion function represents a manipulation feature capable of synchronously controlling multiple robots to manage a range of loads. Within this function, numerous similar robots can be interconnected, programmed, and operated using a single controller within a unified coordinate system [7-9].

From the literature review provided above, several studies and prevalent practices involve employing identical types of robot arms for task execution across various domains, encompassing activities like pick-and-place operations, assembly, material handling, packaging, welding, quality inspection, surgical procedures, and entertainment applications. However, the limited availability of cooperative motion functionalities constrains projects and research endeavors that explore collaboration between different robot arms. Therefore, in this study, two robot arms with distinct software interfaces, speeds, degrees of freedom, and input/output connection requirements will be employed to effectively accomplish a designated task. The task involves each robot arm individually grasping a platform track secured within a specialized holder, facilitating the smooth and secure movement of a slot car along one side of the track. To orchestrate the sequential transfer of the slot car, a Programmable Logic Controller (PLC) will be utilized to manage signal transmission and reception among all components detailed in this study. Moreover, the study aims to demonstrate the feasibility of collaboration between different robot arms, showcasing their ability to successfully execute diverse tasks without relying on cooperative motion functions.

2. Approach and Framework of the Study

The sequential transfer of the slot car was chosen as the experiment's approach because it effectively demonstrates collaboration between two different robot arms without requiring complex cooperative motion functions. Unlike other methods that rely on synchronized controllers or AI-driven coordination, this approach allows a PLC to manage task execution step by step, ensuring smooth operation despite differences in software, speed, and degrees of freedom [1-2]. Additionally, the slot car system provides a controlled, safe, and scalable testing environment using readily available components, making it a practical choice over more complex alternatives [5-6].

The study takes several steps to achieve its goals. Initially, a conceptualization for this study centers on the collaboration of two robot arms to perform a designated task using three distinct coordinate systems: world, joint, and tool coordinate systems. The world coordinate system defines movement along the X, Y, and Z axes, providing a global reference for positioning. The joint coordinate system allows independent control of each robotic joint to reach specific positions, while the tool coordinate system ensures precise end-effector alignment by applying homogeneous transformations. These transformations adjust the local tool frame relative to the robot's motion, compensating for positional offsets and ensuring accurate tool positioning [10]. To achieve this level of precision, forward and inverse kinematics are utilized to compute joint angles and tool positions in real time. Additionally, transformation matrices convert coordinates between different reference frames, allowing both robots to adjust their grip and placement dynamically. This feature reduces positioning errors and enhances accuracy, ensuring seamless interaction with the slot-car system.

Following the conceptualization, the necessary components are selected based on laboratory resources and market availability. The system's design is dictated by the specifications of key components, including robot arms, a Programmable Logic Controller (PLC), and a slot-car. These elements guide the development of crucial subsystems, such as task execution strategies, PLC programming, robot arm motion control, platform holders, and a handheld controller. Additionally, aluminum blocks are machined to fabricate platform holders, ensuring a secure and stable grasp of the track sections. This structural stability is essential for maintaining accuracy in the robotic task execution.

Thirdly, upon acquiring all necessary components, the assembly process begins. This phase involves wiring and electrical integration, ensuring reliable power distribution and proper communication between components. The experimental setup is arranged to position the robotic system within a controlled environment, allowing for precise calibration. End-effector installation and calibration follow, ensuring that the robotic tools function accurately within their designated workspace. If necessary, component modifications are performed to optimize performance, such as structural reinforcements, sensor realignments, or mechanical adjustments.

Furthermore, with the system assembled, ladder diagram programming is implemented within the PLC to coordinate and synchronize robot movements. The control logic includes sequence control to ensure step-by-step execution of tasks, interlocks to prevent conflicting actions between the robots, and error handling mechanisms to detect and respond to faults in real time. To maintain accurate tool positioning throughout the task, coordinate transformations are incorporated, enabling smooth transitions between reference frames. These transformations ensure that the robots interact seamlessly with the slot-car system, dynamically adjusting their grip and placement while minimizing errors. Additionally, real-time motion adjustments, feedback loop integration, and synchronization logic are implemented to enhance system efficiency and reliability.

Finally, the system then undergoes testing and validation to verify its accuracy and reliability. Multiple trials are conducted to assess the precision of coordinate transformations, end-effector alignment, and overall task execution. Error compensation techniques are applied to fine-tune movement accuracy, with necessary adjustments made to optimize performance. Through this iterative process, the system achieves the required precision for successful task execution.

3. Experimental Structure

The experimental setup incorporates components sourced both commercially and from laboratory inventory. Those obtained from the laboratory include the Articulated Robot Arm, Selective-Compliance Assembly Robot Arm (SCARA), Programmable Logic Controller (PLC), PLC modules, and DC power supply. Conversely, commercially available components encompass the slot car, platform tracks, and inductive sensors.

3.1.1 Robot Arms

The spectrum of industrial robots encompasses various types, including cartesian, cylindrical, polar, SCARA, articulated, and delta configurations. In this experiment, cooperative task execution employs articulated and SCARA robot arms manufactured by HIWIN Technologies Corporation. The HIWIN Articulated Robot Arm, weighing 30 kilograms and featuring six axes, boasts a maximum payload capacity of 5 kilograms. Controlled by the RCA605-GB system, it excels in executing intricate tasks within hazardous environments. With a digital signal capacity of up to 24 terminals for both input and output, this robot necessitates a distinct power source for its input/output signals and connected devices [11-12]. On the other hand, the HIWIN Selective-Compliance Assembly Robot Arm, weighing 22 kilograms and equipped with four axes, supports a maximum payload of 6 kilograms. Operated via the HRC-S410 system, it specializes in high-precision tasks. With a digital signal capacity of 8 terminals each for input and output, this robot features an internal power panel supplying 24 VDC and a single-point current of 100 mA, eliminating the need for separate power provision for external signals and devices [13-14].

3.1.2 Programmable Logic Controller

A Programmable Logic Controller (PLC) serves as a standardized programming interface featuring integrated inputs and outputs, controllable through either ladder diagrams or sequential flow charts created by installed software on a computer. In this experiment, a PLC manufactured by Mitsubishi Electric Corporation is utilized to manage devices and signals connected to it, enabling functions such as transmission, reception, and toggling on/off. The setup comprises one PLC along with two expansion modules: the FX2N-32MR-ES/UL, FX2N-16EX, and FX2N-8EYR-ES.

The FX2N-32MR-ES/UL operates as a relay output type programmable controller equipped with 24VDC inputs configurable as a sink or source. It requires a maximum of 30 VDC or 240 VAC for a relay output-rated power supply. Featuring 16 digital inputs and outputs, this controller's signal handling capabilities extend via expansion PLC modules, managing signals from various components including inductive sensors, push buttons, LEDs, DC power supply, and articulated robot arm inputs and outputs.

The FX2N-16EX and FX2N-8EYR-ES are digital expansion blocks that are attached directly to the main PLC module. The FX2N-16EX offers 16 inputs while the FX2N-8EYR-ES provides 8 outputs. These expansion modules are tasked with signal management for the SCARA robot arms. Notably, separate PLC modules are designated for the articulated robot arm's input and output connections due to its requirement for distinct power supplies for both inputs and outputs.

3.1.3 Platform Tracks and Slot-car

The platform tracks consist of molded plastic material featuring slots or grooves designed to guide the slot car during its movement. Adjacent to these grooves, DC-powered metal strips are affixed to conduct power via pick-up braids situated alongside the round guide blade beneath the front section of the slot car. Conversely, the slot car functions as a miniature vehicle propelled by a DC motor linked to a gear transmission for rear-wheel drive, powered through the braids. Additionally, detachable magnets within the slot cars enhance downward force, preventing detachment from the platform track at higher velocities. In this experiment, the slot car must exhibit the ability to halt rapidly upon power supply cessation and resume operation smoothly upon reactivation.

3.1.4 Sensors

The inductive sensor operates as a proximity switch adept at detecting metal objects through electromagnetic induction while being incapable of sensing non-metallic objects, liquids, or materials lacking interaction with magnetic fields. Employed in the experiment, the sensor is a 24 VDC normally closed square inductive sensor with a 4-millimeter sensing distance [15]. Four inductive sensors are affixed to one end of the platform tracks, where the slot car advances. Their role is to identify the bolt positioned beneath the slot car and interrupt the voltage supply to the platform tracks to prevent the slot car from descending.

3.1.5 Power Supply

The direct current power supply functions as an electrical apparatus that transforms alternating current into direct current, providing a stable DC voltage to a load or component. Utilizing the programmable logic controller, this device is deployed to furnish appropriate DC voltage to the metal strips positioned on the platform tracks, ensuring the safe and prompt fulfillment of the transfer motion requirements.

3.2 System Design

The system's signal distribution, illustrated in Fig. 1, outlines the communication pathways between components. Each component utilized in the experiment interfaces with the Programmable Logic Controller (PLC). A computer is responsible for converting the programmed instructions into the PLC's memory. The handheld controller receives signals indicated by LED illumination and transmits them through button presses. In orchestrating the sequential response of the robot arms, signals from the PLC dictate the execution of predefined programs, while updates on the robot arms' current positions are relayed back to the PLC. To ensure an appropriate voltage supply to the slot car, a DC power supply is linked to one of the PLC's common output supply terminals. This arrangement allows the PLC to regulate the voltage supplied to the slot car via the platform tracks following its programmed instructions. Lastly, the inductive sensors provide continuous feedback to the PLC, signaling the detection of the slot car during transfer motion.

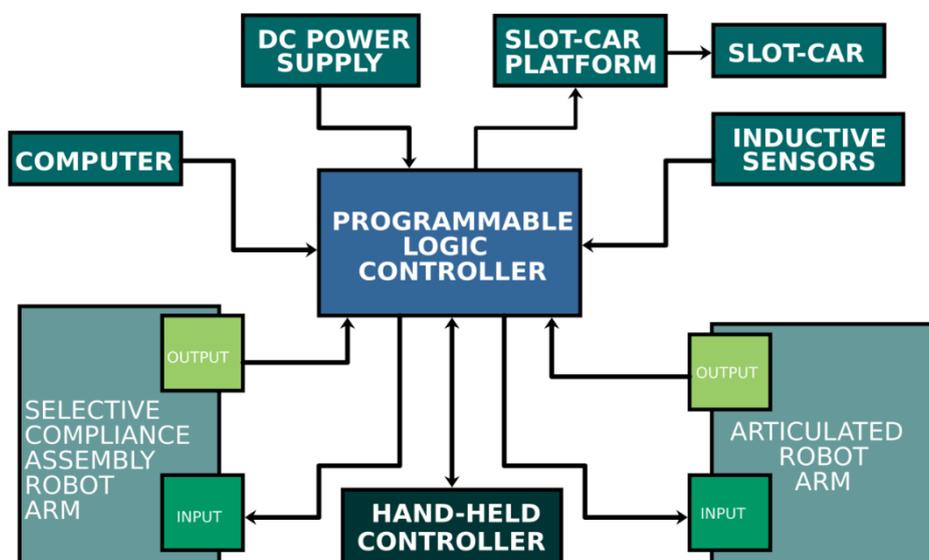


Fig. 1 System's layout of component's signal distributions

The experiment entails three programs: the PLC program, the Articulated Robot Arm program, and the SCARA program. Table 1 details the functions of digital inputs and outputs utilized in the ladder diagram of the Programmable Logic Controller (PLC), created using MELSOFT GX Developer Software. Tables 2 and 3, on the other hand, outline the digital inputs and outputs utilized in the individual programs designed for the articulated robot arm and SCARA, respectively.

Table 1 Programmable logic controller input/output representations

Input	Description	Output	Description
X0	Loading button	Y0	Go to home position (Articulated)
X1	Unloading button	Y1	Go to the loading position (Articulated)
X2	Start/home button	Y2	Go to 2 nd position (Articulated)
X3	Prepare to unload the button	Y3	Go to 1 st position (Articulated)
X4	Sensor 1 signal (SCARA-left)	Y4	Prepare to unload (Articulated)
X5	Sensor 2 signal (SCARA-right)	Y5	Go to the unloading position (Articulated)
X6	Sensor 3 signal (Articulated-left)	Y6	SCARA sensors (Articulated)
X7	Sensor 4 signal (Articulated-right)	Y7	Articulated sensors (Articulated)
X10	Ready to unload (Articulated)	Y10	Start/home LED light
X11	Reached home position (Articulated)	Y11	Loading LED light
X12	Reached 1 st position (Articulated)	Y12	Unloading LED light
X13	Reached 2 nd position (Articulated)	Y13	Prepare to unload LED light
X14	Reached unloading position (Articulated)	Y17	Car power supply
X17	Reset button	Y21	Go to home position (SCARA)
X20	Reached home position (SCARA)	Y22	Go to 2 nd position (SCARA)
X21	Reached 1 st position (SCARA)	Y23	Go to 1 st position (SCARA)
X22	Reached 2 nd position (SCARA)	Y24	Prepare to unload (SCARA)
X23	Reached unloading position (SCARA)	Y25	Go to unloading position (SCARA)
X24	Ready to unload (SCARA)	Y26	SCARA Sensors (SCARA)
		Y27	Articulated Sensors (SCARA)

Table 2 Articulated robot arm input/output representations

Input	Description	Output	Description
DI 1	Articulated sensors	DO 20	Ready to unload
DI 2	SCARA sensors	DO 21	Reached home position
DI 3	Go to the unloading position	DO 22	Reached 1 st position
DI 4	Prepare to unload	DO 23	Reached 2 nd position
DI 5	Go to 1 st position	DO 24	Reached unloading position
DI 6	Go to 2 nd position		
DI 7	Go to the loading position		
DI 8	Go to home position		

Table 3 SCARA input/output representations

Input	Description	Output	Description
DI 1	Articulated sensors	DO 1	Reached home position
DI 2	SCARA sensors	DO 2	Reached 1 st position
DI 3	Go to the unloading position	DO 3	Reached 2 nd position
DI 4	Prepare to unload	DO 4	Reached unloading position
DI 5	Go to 1 st position	DO 5	Ready to unload
DI 6	Go to 2 nd position		
DI 7	Go to home position		

3.2.1 Task Execution Process

The process of executing the task for slot-car transfer incorporates human interaction, empowering the operator to initiate steps in the system's program, as depicted in Fig. 2. Initially, the robot arms are positioned at calibrated home positions. To load the slot car, one of the robot arms is designated to move to the loading position and retrieve the slot car from the operator. Once the slot car is placed on the platform track, preparation for slot-car transfer commences, directing the robot arms to the first transfer position. Upon arrival, the transfer motion phase ensues, facilitating the repetitive transfer of the slot car between platforms. To halt the transfer motion, the operator commands the program to proceed to the next step, initiating preparation for slot-car unloading. This step ensures the completion of the final transfer motion to prevent the slot car from halting mid-track. Subsequently, the operator conducts the unloading of the slot car, retrieving it from the experimental area. Finally, the robot arms return to their home positions following the retrieval of the slot car.

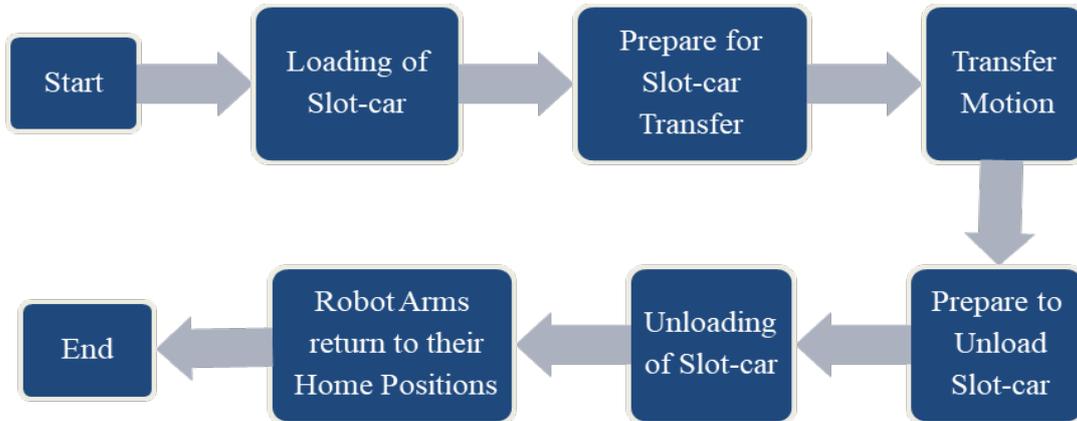


Fig. 2 Task execution flow chart

3.2.2 Transfer Motion

Fig. 3 illustrates the mechanism for transferring the slot car during the transfer motion. Two potential routes are available for the slot car on the platform tracks, determined by the operator's choice during the loading process. Initially, the platform tracks are aligned side by side, and power is supplied to the slot car. Upon detection of the slot car by the inductive sensor on the first platform, the robot arms advance to the subsequent position after a brief delay.

For safety measures, the power supply to the platform tracks is deactivated momentarily once the inductive sensor on the first platform detects the slot car, and it is reactivated once the robot arms reach their programmed position. The transfer motion is recurrently executed by the system and can only be halted by pressing the "prepare to unload" button, enabling the robot arms to complete the final transfer motion and prevent the slot car from halting midway between platforms.

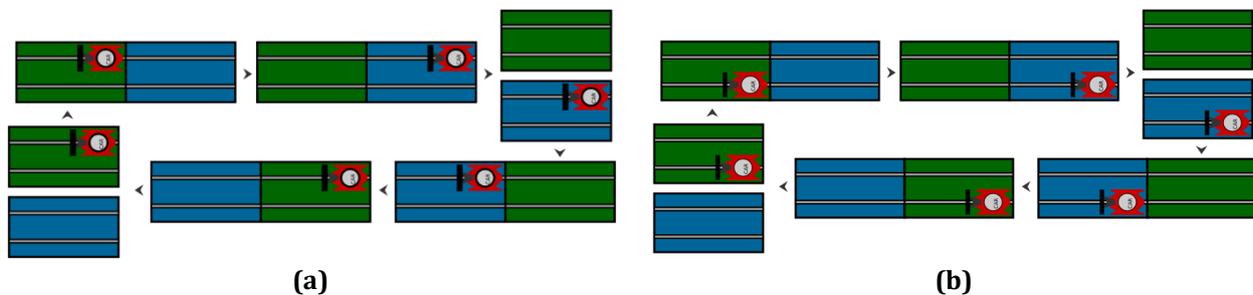


Fig. 3 (a) Slot-car at the left side of the platform tracks; (b) Slot-car at the right side of the platform tracks

3.2.3 Platform Holder

Fig. 4 exhibits two aluminum platform holders, custom-machined and engineered to function as end-effectors for both the articulated robot arm and SCARA, enabling them to manipulate the platform tracks. The design of these holders is tailored to fit the dimensions of the robot arms' ends and the platform tracks.

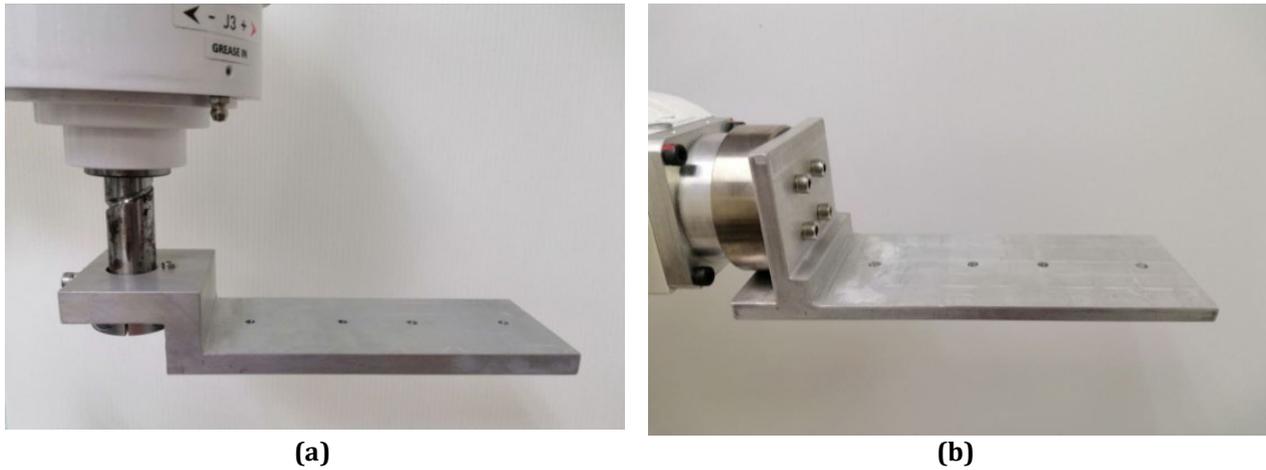


Fig. 4 (a) SCARA platform holder; (b) Articulated robot arm platform holder

3.2.4 Handheld Controller

The handheld controller, depicted in Fig. 5, plays a crucial role in overseeing the operations involved in executing the programmed slot-car transfer task. Comprising four LEDs corresponding to four push buttons, this device facilitates control over the system's program. The LEDs serve to indicate which button is available for operator input, while the push buttons themselves are employed to manipulate the program. A unique color and command distinguish each push button: green signifies the "start/home button," red designates the "prepare to unload button," the first yellow button serves as the "loading button," and the second yellow button acts as the "unloading button."



Fig. 5 Actual handheld controller

3.3 Wiring System

The wiring configuration of the system, outlined in Fig. 6, follows a systematic arrangement. Each inductive sensor is equipped with three wires: brown for 24 VDC, red for signal, and blue for 0 VDC. The PLCs are centrally positioned on the board, with the output terminals of the two robot arms situated adjacent to the input "X" terminal of the PLC. Conversely, the input terminals of the robot arms are positioned adjacent to the output "Y" terminal of the PLC. The system employs American Wire Gauge (AWG) 18 for signal connections across all components. To ensure proper component connection, sourcing-type or sinking-type connections are utilized for the PLC, catering to the requirements of other connected devices within the system. Additionally, the PLC serves as the primary supplier of 24 VDC power to every component, except for the power supply designated for the platform tracks, which necessitates a lower voltage provided by a separate power supply.

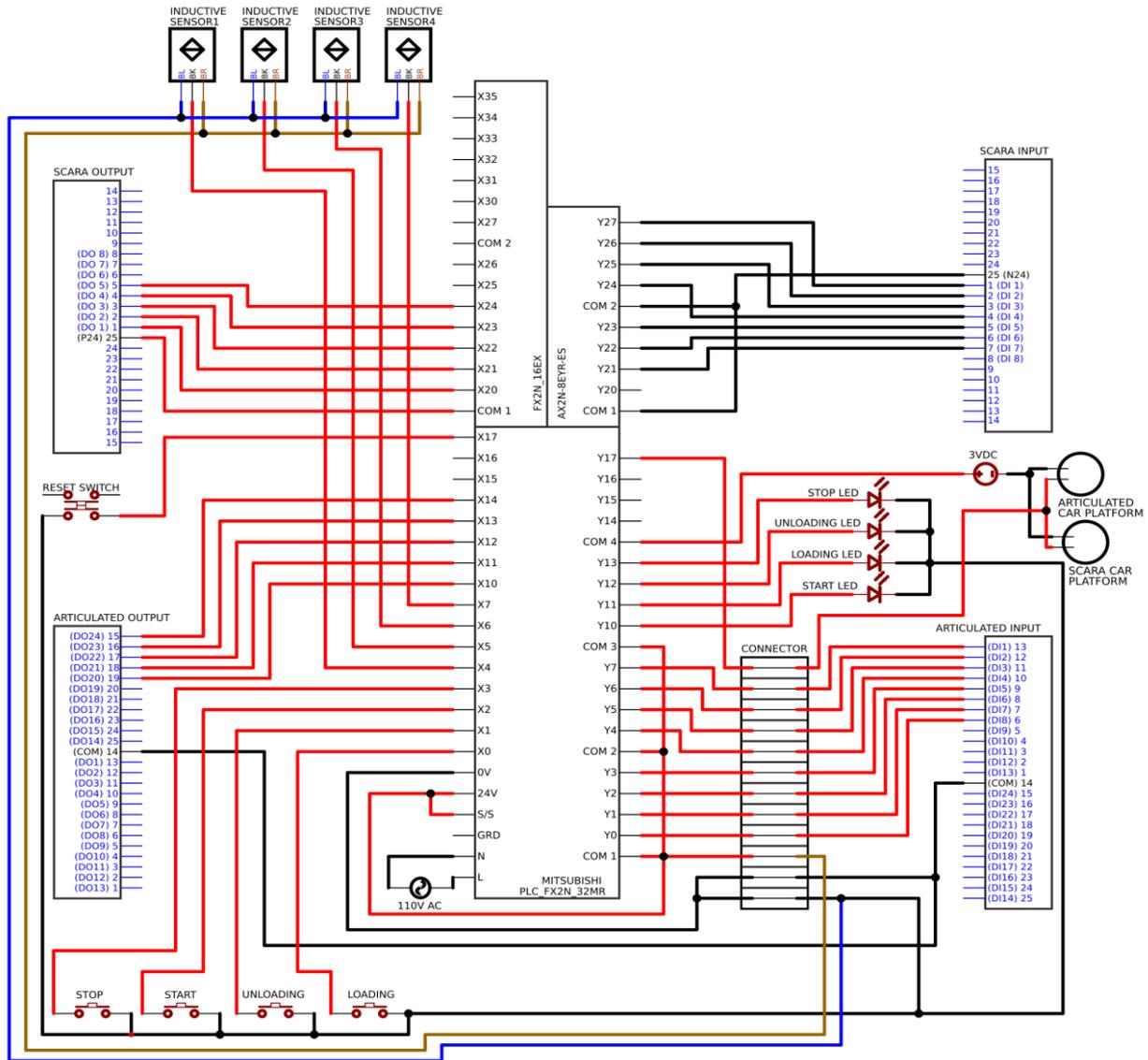


Fig. 6 Actual handheld controller

4. Results and Discussion

Fig. 7 presents the sequential function chart for the slot-car transfer task, consisting of four movements: loading, transfer motion, preparing to unload, and unloading. To prevent potential collisions, the robot arms are first calibrated to new home positions, as shown in Fig. 8(a), since the original positions pose safety risks during operation.

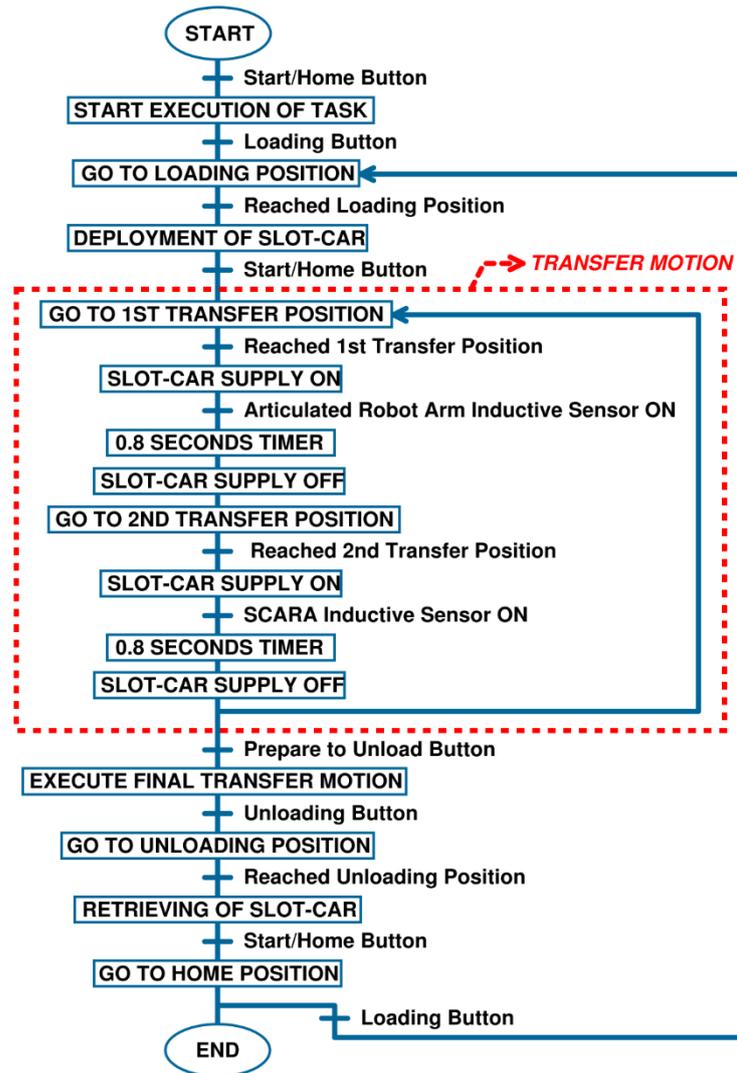


Fig. 7 Sequential function chart

To start the program, the start/home LED illuminates, indicating that the robot arms are in their calibrated home position before initiating the task as shown in Fig. 8(b). Pressing the start/home button begins task execution, triggering the loading LED, which signals readiness for the loading process. Fig. 9 details this procedure. When the loading button is pressed, the articulated robot moves to the loading area, allowing the operator to place the slot car into the experimental setup. The operator then selects whether the slot car will run on the left or right side of the platform throughout the task.

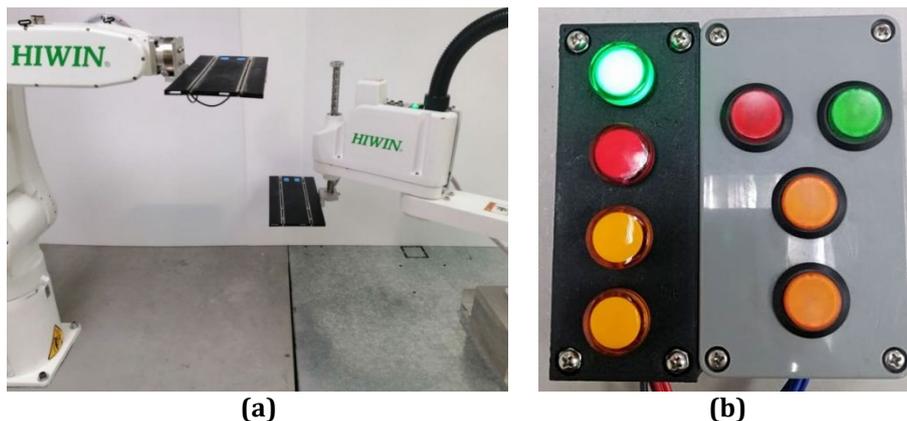


Fig. 8 (a) Initial position of robot arms-home position; (b) Ready to start process indication



Fig. 9 Loading process

The transfer motion process, shown in Fig. 10, begins with the second press of the start/home button. The robot arms move simultaneously to their first transfer positions, triggering the DC power supply to activate and propel the slot car toward the SCARA platform. As the slot car reaches the end of the articulated platform track, an inductive sensor detects its presence, deactivating the DC power supply after 0.8 seconds, stopping the slot car near the SCARA platform midpoint. The robot arms then proceed to their second transfer positions, and this process continues until the prepare-to-unload process is initiated by pressing the prepare-to-unload button, as shown in Fig. 11.

The prepare-to-unload LED signals the execution of the final transfer motion during the prepare-to-unload process, which returns the robot arms to their initial transfer positions. After a 2-second delay, the DC power supply reactivates for the final time, guiding the slot car onto the SCARA platform for unloading. As the slot car reaches the end of the articulated platform, the inductive sensor detects it and deactivates the DC power supply after 0.8 seconds. Another 2-second delay occurs before the robot arms transition to their ready-to-unload positions, initiating the unloading process shown in Fig. 12.

When the robot arms reach their ready-to-unload positions, the unloading LED illuminates, signaling readiness for user input. Pressing the unloading button prompts the SCARA robot to move to the unloading position, while the articulated robot arm remains stationary. Once the SCARA robot reaches the unloading area, the operator retrieves the slot car and presses the start/home button, returning the robot arms to their calibrated home positions to complete the cycle.

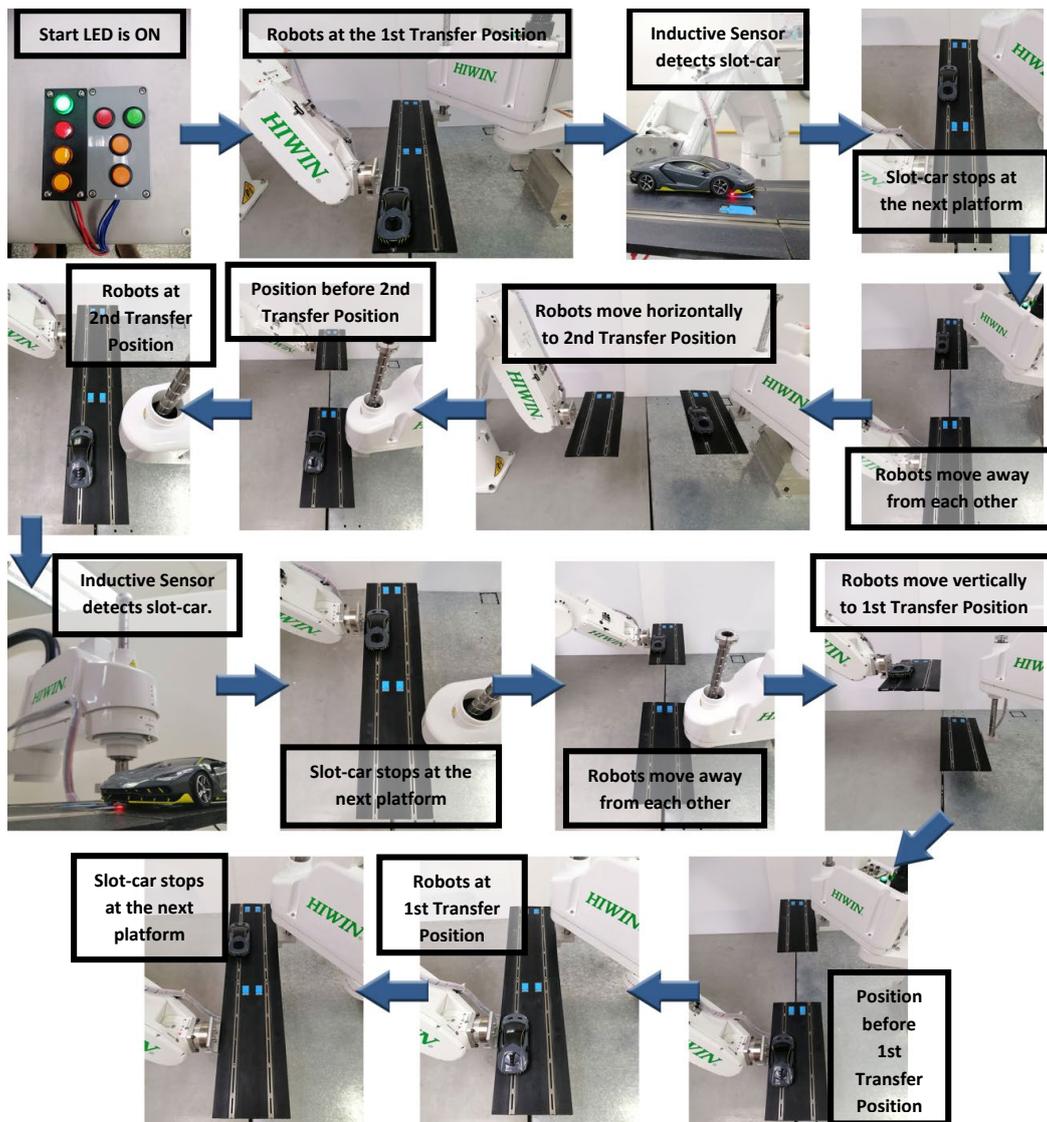


Fig. 10 Transfer motion process

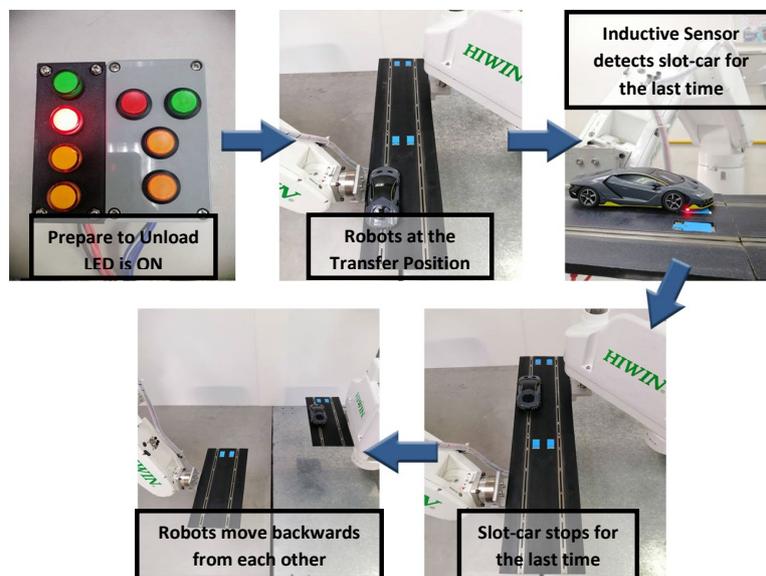


Fig. 11 Prepare to unload process

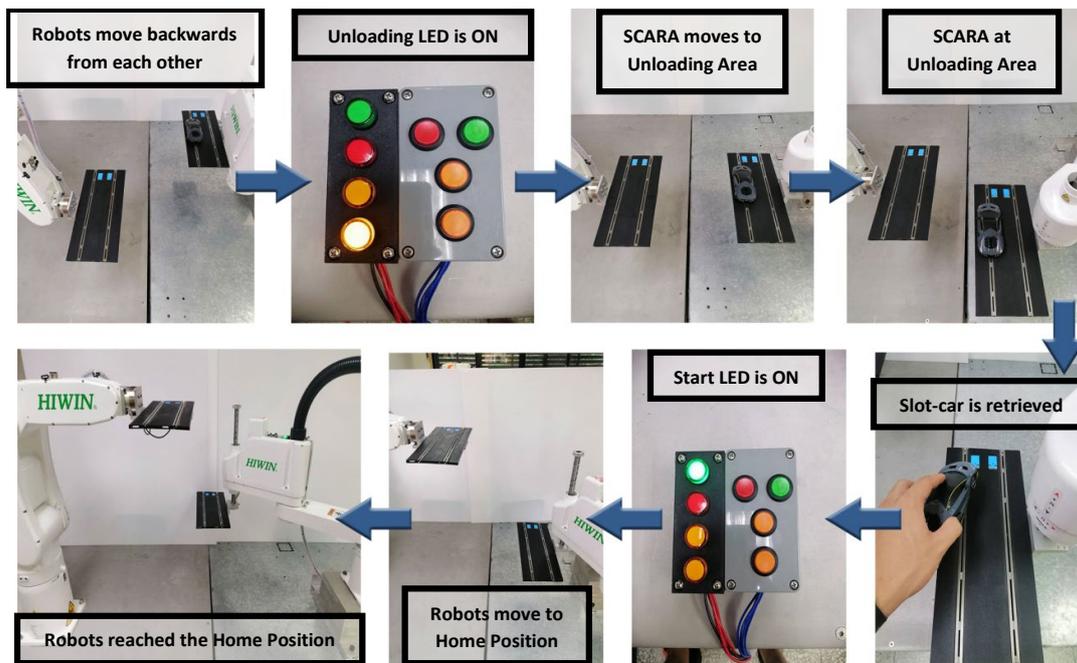


Fig. 12 Unloading process

The integration of identical robots in industrial automation is well-established, particularly in synchronized operations such as assembly, material handling, and automated production lines [1-2]. These systems benefit from uniform kinematics and pre-defined motion algorithms to maintain efficiency and precision. However, coordinating robotic arms with different engineering designs presents a significant challenge due to variations in control systems, degrees of freedom, and the lack of built-in cooperative motion functions, limiting adaptability in complex industrial environments [3].

This study addresses these challenges by developing a PLC-controlled coordination framework for a SCARA and an articulated robot arm, enabling precise synchronization in a slot-car transfer system without relying on proprietary cooperative motion features. Unlike conventional methods that depend on synchronized controllers, this approach utilizes an external PLC to govern the sequential movements of both robotic arms. By leveraging laboratory and commercially available components, the study ensures compatibility and synchronization through a detailed analysis of I/O signal mapping, voltage matching, and mechanical adaptation.

A critical limitation identified is the absence of universal internal power panels in robotic arms, leading to potential electrical inconsistencies—a challenge also noted in previous robotic system integration studies [4-5]. Additionally, restricted digital input and output terminals complicate the management of multiple components, an issue observed in multi-robot systems research [6]. This study demonstrates how PLCs effectively mitigate these hardware constraints by simplifying signal processing, reducing wiring complexity, and minimizing the need for additional I/O modules [7].

Experimental results validate the feasibility of the proposed PLC-controlled coordination method, reinforcing findings from previous studies that demonstrate the effectiveness of external controllers in synchronizing heterogeneous robotic systems [8-9]. While most research has focused on coordinating identical robots, this study extends the field by proving that robotic arms with different control interfaces and degrees of freedom can achieve synchronized task execution through structured PLC control. By providing a scalable and adaptable framework for managing power distribution, signal processing, and sequential task execution, this study enhances existing knowledge on non-cooperative robotic integration and offers practical solutions for real-world industrial automation applications.

5. Conclusion

The slot-car transfer system successfully demonstrated PLC-controlled coordination between a SCARA and an articulated robot arm without relying on built-in cooperative motion functions. By implementing a structured PLC framework, the system synchronized two robotic arms with distinct engineering designs and degrees of freedom, validating the feasibility of external controllers for coordinating heterogeneous robots in non-cooperative tasks.

A comprehensive analysis of component specifications ensured seamless integration, addressing I/O signal mapping, voltage matching, and mechanical adaptation. Compatibility between robot arms, PLC modules, DC power supplies, inductive sensors, and platform tracks was rigorously evaluated. Safe wiring and installation

followed university PLC course guidelines and HIWIN user manuals, mitigating electrical and operational inconsistencies.

The PLC-based control system effectively managed sequential coordination through pre-programmed delays, sensor feedback loops, and independent motion trajectories, enabling precise and repeatable task execution. Custom platform holders enhanced stability during slot-car transfers, ensuring reliable grasping and placement across platform tracks. Despite challenges in wiring complexity and hardware constraints, in-depth analysis of specifications, manuals, and software configurations facilitated smooth system operation and integration.

This study reinforces the viability of PLCs as a robust control solution for synchronizing diverse robotic arms in industrial automation without proprietary cooperative motion functions. By addressing key hardware limitations and optimizing signal distribution, the proposed framework offers a scalable and adaptable approach for non-cooperative robotic integration, providing practical insights for industrial applications and future advancements in PLC-based multi-robot systems.

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Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

References

- [1] Angeles, J. (2006). *Fundamentals of Robotic Mechanical Systems: Theory, Methods, and Algorithms* (3rd Ed.). New York: Springer-Verlag New York Inc.
- [2] Fu, K.S., Gonzalez, R.C. & Lee, C.S.G. (1987). *Robotics Control, Sensing, Vision, and Intelligence*. Singapore: McGraw-Hill Book Co.
- [3] Morecki, A. & Knapczyk, J. (1999). *Basics of Robotics: Theory and Components of Manipulators and Robots*. New York: Springer-Verlag Wien.
- [4] Borst, C., Ott, C., Wimbock, T., Brunner, B., Zacharias, F., Bauml, B., Hillenbrand, U., Haddadin, S., Albu-Schaffer, A., & Hirzinger, G. (2007). A humanoid upper body system for two-handed manipulation. *Proceedings 2007 IEEE International Conference on Robotics and Automation*, 2766-2767, <https://doi.org/10.1109/robot.2007.363886>
- [5] DENSO Robotics. (2012, August 3). *DENSO Robotics-Robots lay out slot-car track* [Video]. Youtube. <https://www.youtube.com/watch?v=vY7j76FMds0>
- [6] Kruger, J., Schreck, G., & Surdilovic, D. (2011). Dual arm robot for flexible and cooperative assembly. *CIRP Annals-Manufacturing Technology*, 60, 5-8, <https://doi.org/10.1016/j.cirp.2011.03.017>
- [7] Denso Robotics Incorporated. (2024). Cooperative Control. <https://www.densorobotics-europe.com/product-overview/products/robotics-functions/cooperative-control>
- [8] DENSO WAVE. (2016, September 5). *DENSO Robot Function "Cooperation Control Function"* [Video]. Youtube. https://www.youtube.com/watch?v=18sC1P_lgnM&feature=youtu.be
- [9] Chien-Pin Chen. (2015, July 23). *Cooperative Function of PMC Multi Robot Controller - Geometric Coupling* [Video]. Youtube. <https://www.youtube.com/watch?v=gVB1T9lgRCw>
- [10] Niku, S. (2001). *Introduction to Robotics: Analysis, Systems, Applications*. New Jersey: Prentice Hall, Inc.
- [11] HIWIN Technologies Corporation. (2018). SCARA Robot Controller User Manual. [https://www.hiwin.tw/download/tech_doc/mar/SCARA_Robot_RS403_Controller_Manual-\(E\).pdf](https://www.hiwin.tw/download/tech_doc/mar/SCARA_Robot_RS403_Controller_Manual-(E).pdf)
- [12] HIWIN Technologies Corporation. (2018). Articulated Robot Controller-RCA605 User Manual. [https://www.hiwin.tw/download/tech_doc/mar/Articulated_Robot_Controller_GB_Series_User_Manual-\(E\).pdf](https://www.hiwin.tw/download/tech_doc/mar/Articulated_Robot_Controller_GB_Series_User_Manual-(E).pdf)
- [13] HIWIN Technologies Corporation. (2018). Articulated Robot – RA605-GB, RT605-GB User Manual. https://motioncontrolsystems.hiwin.com/Asset/RART605_User_Manual--E-.pdf

- [14] HIWIN Technologies Corporation. (2018). SCARA Robot – RS406 Maintenance Manual. <https://hiwin.sg/wp-content/uploads/2020/08/SCARA-Robot-RS406-User-Manual.pdf>
- [15] NewBECCA. (2018). Taibang square proximity switch metal sensor switch sensor switch sensor TSW05-N normally open NPN three-line 24V. <https://www.newbecca.com/product/556558636630>