DESIGN AND IMPLEMENTATION OF AN AUTOMATIC PARKING GATE PROTOTYPE SYSTEM BASED ON THE OMRON CP1E-N20 PROGRAMMABLE LOGIC CONTROLLER

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ABSTRACT

This study aims to design and develop a prototype of an automatic parking door crossing system based on the Omron CP1E-N20 Programmable Logic Controller (PLC) which is integrated with Radio Frequency Identification (RFID) and Internet of Things (IoT) technology as an industrial automation learning medium. The system is designed using the concept of input, process, output where the input includes RFID Reader and proximity sensors which are used to detect and identify vehicles. The data is then processed by the Omron CP1E-N20 PLC using a ladder diagram on the CX-Programmer and the ESP-32 using the C++ language on the Arduino IDE. The system output is in the form of a servo motor as an automatic bar drive, LCD as a system status display, ESP-32 Cam as visual monitoring, and a monitoring website to display UID data, access status, time, and vehicle images in real-time. The research methods include observation of the parking system at Solo Square Mall, benchmarking, prototype design, program creation, system testing, cycle time testing using a single-sample t-test, and evaluation using the Failure Mode and Effects Analysis (FMEA) method. The cycle time test was carried out 30 times by comparing the average cycle time of the prototype with a reference value of 8 seconds. The test results showed that the system was able to validate RFID, open and close bars automatically, and send monitoring data to the website properly. The results of the t-test show that the average system cycle time is faster than the reference value so that the system is considered to have good and consistent performance. Furthermore, an evaluation was carried out using FMEA which showed that the system had a good level of reliability after mitigating several potential failures in the main components.

Keywords: Automation, PLC Omron CP1E-N20, Automatic Parking Cross System, Prototype, FMEA

INTRODUCTION

The rapid development of automation technology in the modern industrial era demands human resources who are able to design, understand, and operate automated control systems. In the academic environment, especially in the Industrial Engineering Study Program of the University of Muhammadiyah Surakarta, practical learning media that is oriented to industrial needs is needed. The Industrial Automation course has an important role in equipping students with knowledge about control systems, automation devices, *Programmable Logic Controller* (PLC) programming, and structured system design.

Industrial automation aims to improve the efficiency and operational effectiveness of machines. One of the key components in an automation system is the controller, where the PLC is widely used as the main control unit. PLC is a microprocessor-based control system that executes programmed instructions such as logic operations, sequencing, timing, and enumeration [1] ; [2]. Compared with conventional relay-based systems, PLCs have advantages in terms of reliability, flexibility, and durability, especially in industrial environments that have electrical disturbances, vibrations, and temperature changes [3] ; [4]. In addition, PLCs are also equipped with built-in features such as *timers*, *counters*, and diagnostics that can improve system performance and simplify the maintenance process [5].

In the learning process, students are not only required to understand theoretical concepts, but also be able to implement them into real systems. System design includes the development of hardware and software architectures, sensor and actuator integration, and performance testing to ensure the system can run optimally. In addition, the design process also includes wiring configuration, the preparation of control panels, and work safety aspects which are important competencies in the industrial world [6];[7];[8];[9].

Previous research has discussed PLC-based automation systems and automated parking systems. For example, research by Sadi shows that PLC-based parking systems are able to improve efficiency and monitoring in [10] *real-time*. However, the study uses a different type of PLC and only uses *RFID readers* to monitor parking lot users, so it has not integrated the crossbar control system as the main mechanism for regulating vehicle access.

Therefore, this study aims to design and implement a PLC-based automatic parking door bar system integrated with RFID technology on a laboratory prototype scale. The prototype developed serves as a learning medium to support the understanding of industrial automation concepts and intelligent parking systems. This system is designed to simulate the parking system in real life as well as an interactive learning medium. Through this approach, students can understand the concepts of digital control systems, such as input-output processes, sequence logic, and system integration. In addition, the system is also equipped with an Internet of Things (IoT) feature that allows the monitoring process to be carried out in real-time [11];[12];[13].

The purpose of this research is to design and implement a PLC-based automatic parking door bar system that is focused as a learning medium, so that students can understand the control system, input-output process, sequence logic, and integration between components.

The contribution of this research is the development of laboratory-scale prototype-based learning media designed to help students understand the concept of control systems. Through this system, students can learn and integrate various aspects, such as the input-output process, sequence logic, and integration between components in an automation system.

METHOD

The research was carried out at the Industrial Automation Laboratory, Industrial Engineering Study Program, University of Muhammadiyah Surakarta. The object of this research is to design and create a learning module in the form of a prototype of an automatic parking door bar system on a laboratory scale controlled using PLC Omron CP1E N20.

The research stage is carried out systematically, starting with observation and benchmarking, then continuing to the system evaluation stage.

1. Data Collection

The system design step begins with an observation and benchmarking process. Observations are made on the real parking system to understand the workflow, components used, and the overall operational process of the system. Furthermore, benchmarking is carried out by comparing systems designed against similar systems to identify advantages, disadvantages, and development opportunities that can be applied.

2. Specification

The specification determination stage begins with determining the main components that make up the system such as the Omron CP1E-N20 PLC, proximity sensors, RFID and servo

3. Design Concept Design

The design concept design stage includes designing a system that integrates the vehicle identification process, automatic control, and the mechanism of opening and closing parking bars. The system is designed with the concepts of input, process, and output. The design is made simple, functional, and easy to observe so that it is suitable as a learning medium for industrial automation in the laboratory

4. Program Creation

The program design is carried out to regulate the entire work process of the automatic parking bar system so that it can run according to the flow and function that has been designed. The program is created by integrating PLCs using CX-Programmer and ESP-32 using Arduino Ide as the system control center. PLC is used to set the main control logic, while ESP-32 is used for communication and integration of IOT-based systems.

5. Program Testing

Program testing is carried out to ensure that the entire system is running according to the intended function and workflow. Testing includes communication between devices, input and output response, as well as working synchronization of PLCs, ESP32s, sensors, and actuators. In addition, tests are carried out to detect errors in programming logic, data communication, and system control so that programs can be evaluated and corrected if interference or inconsistencies are found.

6. Prototyping Stage

The prototyping stage is carried out by assembling components according to the specifications that have been designed and integrating all components into one system that can function properly. At this stage, the integration of the program into the system is also carried out to ensure that all components can work in a coordinated manner according to the logic that has been designed.

7. Prototype Testing Stage

The prototype testing phase is carried out to assess the system's performance, including RFID reading accuracy, sensor response, actuator performance, and overall system cycle time. The cycle time is measured from the RFID reading process until the bar closes again after the vehicle passes through the sensor.

8. Evaluation Stage

Furthermore, the system evaluation was carried out using *the Failure Mode and Effects Analysis* (FMEA) method. Each potential failure is analyzed based on *severity*, likelihood of occurrence, and detection ability to obtain *a Risk Priority Number* (RPN) value. This analysis is used to identify critical components and determine corrective actions to improve the reliability of the system [14];[15].

RESULT AND DISCUSION

1. Data Collection

This research was conducted at the UMS Industrial Automation Laboratory with an object in the form of a prototype of an Omron CP1E-N20 PLC-based automatic parking bar system integrated with RFID and IoT. The system works with the concept of input–process–output, where RFID and proximity sensors are the inputs, PLCs as the control center, and parking bars and website monitoring as outputs. Data collection is carried out through observation and benchmarking as a reference in the design of the prototype.

2. Prototype Specification Determination Stage

The prototype specification of the PLC-based PLC Omron CP1E N20 automatic parking door crossing system describes the technical characteristics and the system's ability to automatically control vehicle access using RFID. A prototype consists of three main parts, namely input, process, and output. The input section uses RFID RC522 (13.56 MHz, read distance ±2–5 cm) and proximity sensor (5–24V, detection distance ±2–10 cm) to detect vehicles and receive data. The process part uses the Omron CP1E N20 PLC (24V DC, 20 I/O) with ladder logic on the CX-Programmer and Arduino IDE support for data processing. Meanwhile, the output section consists of a servo motor (5V, 0°–180°), an I2C-based 16x2 LCD, and a website display to run the bar mechanism and display system information.

3. Concept Design Stage

The design of the system design concept in this study is focused on compiling an overview of the overall shape of the tool and the system workflow. This stage aims to conceptually design the system so that it can work according to the expected function, resulting in a visual design of the prototype as well as a structured and systematic process flow. The design includes the integration of input, process, and output components, ranging from vehicle identification using RFID, data processing by PLC, to automatic open-close mechanism of the crossbar, prototype design drawings and trainer kits are presented in figure 1. Prototype Design and Trainer Kit

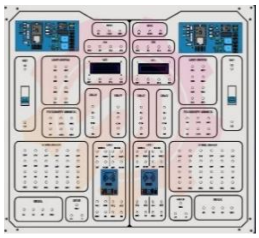

Figure 1. Prototype Design and Trainer Kit

To clarify the workflow of the developed system, a flowchart is presented in Figure 2 which represents the overall stages of the process. This diagram illustrates the integration between system components and the sequence of processes from the input stage, data processing, to the output generated in the PLC-based automatic parking door bar system.

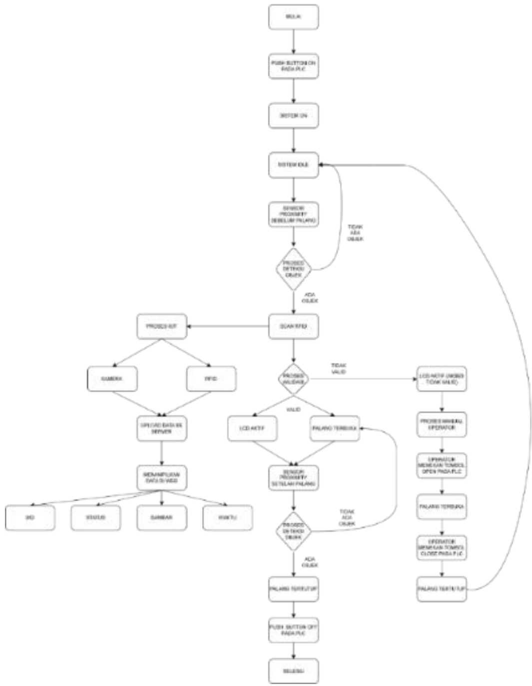

Figure 2. Prototype Workflow Flowchart

The diagram illustrates the workflow of the automated parking bar system integrated with RFID, proximity sensors, cameras, IoT, and PLC. The process starts when the system is activated and is ready. When the vehicle is detected, the user performs an RFID scan which is then validated by the system. If valid, the bar opens, the LCD displays the status, and the IoT system retrieves and sends vehicle data to the web. Once the vehicle passes the crossbar, the sensor will trigger an automatic shutdown. If it is invalid, access is denied and the operator can control the bar manually. The system can be shut down after the entire process is completed.

4. Program Creation Stage

The creation of the program using the ESP32 microcontroller using the Arduino IDE with the C++ language and PLC using the CX-Programmer with ladder diagram.

a. The CX-Programmer program is a ladder diagram, the program works by automatically setting the opening and closing process of bars on the entry and exit lanes based on signals from proximity sensors, RFID, and manual controls.
b. The bridge program is a link between the PLC and the ESP32-based trainer developed using the Arduino IDE (C++). The program integrates RS485 communication, reads inputs from PLCs, as well as controls outputs such as servos and proximity sensors. In addition, ESP32 uses WiFi to send UID data to the server over HTTP, with SPIFFS-based queue support to maintain reliable data transmission.
c. The bar program is an ESP32-based slave system developed with Arduino IDE (C++). This program functions to read RFID, detect vehicles with proximity

sensors, and control the servo as a bar actuator. The system is also equipped with an LCD and buzzer, and communicates with the master via RS485.

d. The ESP-32 CAM program is an ESP32-CAM-based camera streaming system developed with Arduino IDE (C++), which functions to capture images and display real-time video via WiFi (MJPEG).

e. The website program consists of two main components, namely an API for data management and database connections, and a UI dashboard for monitoring.

5. Program Testing Stage

Program testing is carried out by displaying the results of system performance through the website display. The website is used to display the results of system monitoring in real-time. The display in figures 3 and 4 shows the process of monitoring and recording data in real-time and historically.

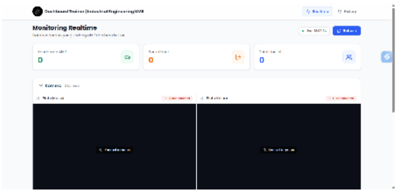

Figure 3. Real-Time Monitoring

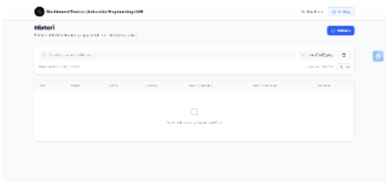

Figure 4. History View

On the Realtime Monitoring display, the system displays the operational conditions directly. There are status indicators such as the number of vehicles entering, exiting, and total activity. In addition, there is a display camera showing so that users can monitor the field conditions directly. In the History view, the system provides a feature of recording data stored in a structured manner. The data displayed includes the time, RFID identity and vehicle image capture.

6. Prototyping Stage

Prototyping is carried out by assembling components according to the specifications that have been designed and integrating all components into one system that can function properly. At this stage, the integration of the program into the system is also carried out to ensure that all components can work in a coordinated manner according to the logic that has been designed. Figure 5 shows a prototype of an automatic parking door crossing system developed as a control system-based learning medium, featuring component integration.

Figure 5. Prototype

The prototype in figure 5 is a trainer kit for an automatic parking door bar system designed as a learning medium for control and automation systems. The system consists of key components such as PLC, ESP-32 and ESP-32 Cam Microcontrollers, relays, proximity sensors, RFID readers, and power supplies that are modular and structured for easy understanding. The parking bar functions as an actuator that is controlled based on inputs from sensors and RFID, thus representing the concept of input–process–output. The integration between components and the use of various modules also demonstrate the practical application of control logic and system communication.

7. Prototype Testing Stage

The prototype testing stage is carried out by analyzing cycle time data using the t-test method to determine the consistency and reliability of system performance. The test aims to compare the average cycle times obtained from 30 experiments, so that it can be found out if the system is working stably and as expected. Table 1 below shows the experimental data used as the basis for the analysis.

Table 1 Cycle Time Data

Yes	Prototype Cycle Time Data(s)	Yes	Prototype Cycle Time Data(s)	No.	Prototype Cycle Time Data(s)
1	5.6	11	9.1	21	9.86
2	5.88	12	5.78	22	5.94
3	5.7	13	5.85	23	6.08
4	5.75	14	6.03	24	5.95
5	6.13	15	5.81	25	5.79
6	6.42	16	6.12	26	6.14
7	5.67	17	7.85	27	9.45
8	6	18	6.5	28	5.79
9	7.5	19	6.42	29	7.13
10	5.97	20	8.56	30	5.79

Table 2. Statistical Test

One-Sample Statistics

	N	Mean	Std. Deviation	Std. Error Mean
waktu_siklus	30	6.5520	1.20512	.22002

Table 3. Test - T

One-Sample Test

	Test Value = 7.71					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
waktu_siklus	-6.581	29	.000	-1.44800	-1.8980	-.9980

Based on the results of the One-Sample Statistics test, the number of test data was 30 data with an average cycle time of 6.5520 seconds and a standard deviation of 1.20512, which showed a relatively stable data variation. A Std. Error Mean value of 0.22002 indicates a low average error rate.

The results of the One-Sample Test with a comparative value of 8 seconds showed a calculated t-value of -6.581 with a Sig. (2-tailed) of 0.000 < 0.05, so that H_0 was rejected and H_1 was accepted. The Mean Difference value of -1.44800 indicates that the average prototype cycle time is 1.448 seconds faster than the reference value. In addition, the value of the confidence interval does not pass zero, so the difference is statistically significant. Based on these results, the prototype of the automated parking system performed well and consistently during the test.

8. Evaluation Stage

Evaluation uses FMEA to identify failures with the Severity, Occurrence, and Detection parameters to generate RPN.

Table 4. FMEA

No	Failure	Causes	Severity	Occurence	Detection	RPN
1	Communication inconsistencies between system components	Communication interruptions between modules	7	5	8	280
2	Program error	Kesalahan ladder diagram	8	4	7	224
3	Data is not sent to the server	Unstable network	7	5	6	210
4	RFID is illegible	Reading distance is not suitable, signal interference	6	3	3	54
5	Immobile Bars	Actuator/wiring malfunction	5	3	3	45
6	Sensors do not detect vehicles	Improper sensor position	6	3	2	36
7	The camera does not take pictures	Connection or camera problems	5	3	2	30

Based on table 4, the highest risk is in the mismatch of communication between system components with an RPN value of 280 which can interfere with data exchange and system performance. The next risk is program errors with an RPN value of 224 that affect the integration of control and monitoring systems, and data not being sent to the server with an RPN value of 210 that hinders real-time monitoring. In addition, there are other risks with lower priority such as unreadable RFID, non-moving bars, sensors failing to detect vehicles, and cameras not taking pictures.

Based on the result of the FMEA analysis, several mitigtation measures are done to reduce the potential failure of the system. Communication mismatches between components are handled by protocol standardization and system integration testing. Program errors are minimized by ladder diagram validation and program logic testing. Data is not sent to the server resolved by using stable networks and offline mode.

CONCLUSION

The research successfully developed a prototype of the Omron CP1E-N20 PLC-based automatic parking bar system integrated with RFID and IoT as an industrial automation learning medium. The system can perform vehicle identification, automatic cross-bar opening, and real-time monitoring. The t-test results showed an average cycle time of 6.55 seconds, faster than the reference value of 8 seconds, while the FMEA evaluation showed that the main risks of the system could be minimized through optimization of communication and system devices. Further development may add features such as real-time parking capacity monitoring, notifications, and mobile app integration. Performance improvements can also be done with the use of higher quality components.

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