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Design and Build of Communication Protocol Trainer Tools on Networks between PLCs and HMIs

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Abstract

With the rapid advancement of science and technology, the role of technology in industry is also increasing, particularly through automation that simplifies and enhances work process efficiency. To support this development, education plays a crucial role in enhancing students' competencies. One relevant subject in industrial technology is Programmable Logic Controller (PLC). In PLC education, trainer tools are used to help students understand industrial control concepts. At Politeknik Manufaktur Bandung, particularly in the Mechatronics and Automation Engineering Technology programs, the use of PLC trainers is still limited to basic input-output features. Survey results show that most students only understand Ethernet communication protocol and have never connected more than one PLC in a single system, resulting in a limited understanding of inter-PLC communication. This research aims to develop a trainer that teaches various PLC communication protocols, including Controller Link, DeviceNet, Serial RS-232C, and Ethernet, with inter-PLC and HMI communication implementation. The system uses three PLCs, where an Omron CP1H PLC as the master uses Controller Link to communicate with another Omron CP1H PLC as a slave, DeviceNet for remote slave devices, Serial RS-232C to communicate with an Omron CJ2M PLC as a slave, and Ethernet connected to Human Machine Interfaces (HMI) Omron NB7W and Kinco GL070E for PLC data monitoring. Based on the assessment results, the overall trainer tool evaluated received an effectiveness score of 95.1% from 6 aspects of the assessment. This trainer is expected to enhance students' understanding of PLC communication protocols and their applications in integrated systems.

Introduction

Along with the progress of the industrial revolution based on the development of science and technology that is growing rapidly (Sanusi, 2019). One tangible evidence of this development is automation, which utilizes technology to simplify, ease, and improve the efficiency of work processes. Education is one way to master the continuous development of technology (Razik & Almasri, 2023). One of the lessons in education that discusses technology and industrial automation is Programmable Logic Controller (PLC). In learning, trainer tools are used to support the delivery of educational messages or information through software assisted by hardware, so that these messages or information can be accessed by students properly (Jawahir & Alfita, 2020; Moto, 2019; Ramadani & Almasri, 2023). PLC trainer is a device used for learning and learning how to operate controls on a PLC (Mugono & Musyahar, 2021; Permatasari et al., 2023). The use of learning media in the learning process can increase new

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interest and motivation, and have a psychological impact on students (Gunawan & Ritonga, 2019; Katona et al., 2022; Puspitarini & Hanif, 2019; Afifa & Astuti, 2024).

Politeknik Manufaktur Bandung (POLMAN Bandung), in the Study Program Teknologi Rekayasa Mekatronika and Teknologi Rekayasa Otomasi, Department of Teknik Otomasi Manufaktur dan Mekatronika, is also trying to implement PLC through its learning. Based on the results of observations and surveys in the Department of Teknik Otomasi Manufaktur dan Mekatronika, the observation results show that the PLC trainer tools used are still simple and limited to displaying input output features on the PLC they use. The survey results show that 90.9% of the 11 student respondents who have studied PLCs only know the Ethernet communication protocol as a type of communication used in PLCs. Then 10 out of 11 students have never communicated 2 or more PLCs and HMIs in one system. As a result, students do not have a concrete understanding because there are no educational resources that implement industrial settings in the classroom, about communication between PLCs using the appropriate communication protocol. From these problems, a trainer tool is needed that can make students better understand the types of communication protocols in PLCs and apply them to communication between PLCs integrated with the Human Machine Interface (HMI).

This research aims to create a learning media in the form of a trainer tool that explains several communication protocols in PLC, namely Controller Link, DeviceNet, RS-232C Serial and Ethernet with the implementation of communication between PLC and HMI. In addition, the system designed uses 3 PLCs. The Omron CP1H PLC is used as the master by using the Controller Link communication protocol to communicate with other Omron CP1H PLCs as slaves, DeviceNet is used to communicate with sensors and actuators that are far away from the Master PLC, and Serial RS-232C to communicate the Omron CP1H master PLC with the Omron CJ2M PLC as a slave, and Ethernet is connected to the Omron NB7W and Kinco GL070E HMIs to monitor PLC data.

Methods

Hardware Design

This research uses the VDI 2206 design research method in technical aspects. VDI 2206 is a methodology in designing mechatronic system designs (Rokhim et al., 2021). This method includes several stages, including Requirements, System design, Domain-specific design, System integration, Verification/validation, Modeling and model analysis, and Product analysis (Maulana et al., 2022).

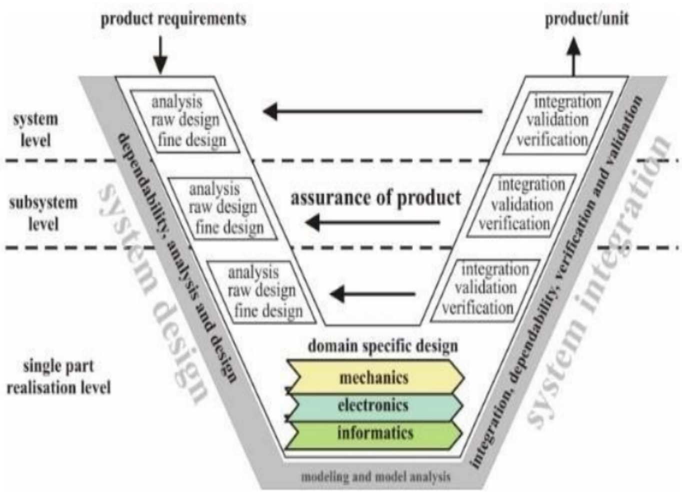

Figure 1. Mechatronics System Design Guide

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In Figure 1 there are several stages in designing a mechatronics system. Requirements stage is the process of analyzing problems, analyzing system needs, and research objects defined and recorded in a requirements form (Moto, 2019). System design stage is the process of designing the system by producing solutions for each sub-system of the problem that has been defined on the part function diagram (Wigenaputra et al., 2023; Barbieri et al., 2014). The Domain-specific design stage is a combination of each sub-system designed in relation to detailed object design to ensure the performance and function of each sub-system is good, so that the designed system can be tested for each sub-system or combination of sub-systems with good performance (Aminahet al., 2019). System integration stage is the process of integrating all sub-systems into a complete system (Nugraha et al., 2019). Integration between sub-systems is done by experimenting with the performance of each sub-system, then connecting each sub-system into a whole system that performs the main function. The Verification/validation stage is a process of continuously monitoring the design to ensure that each sub-system has built good performance according to predetermined requirements parameters (Aminah et al., 2019; Tavčar et al., 2019). The Modeling and model analysis stage is the process of modeling and analyzing system characteristics using software to be simulated (Maulana et al., 2019). The Product stage is the final process that produces the product according to the steps taken.

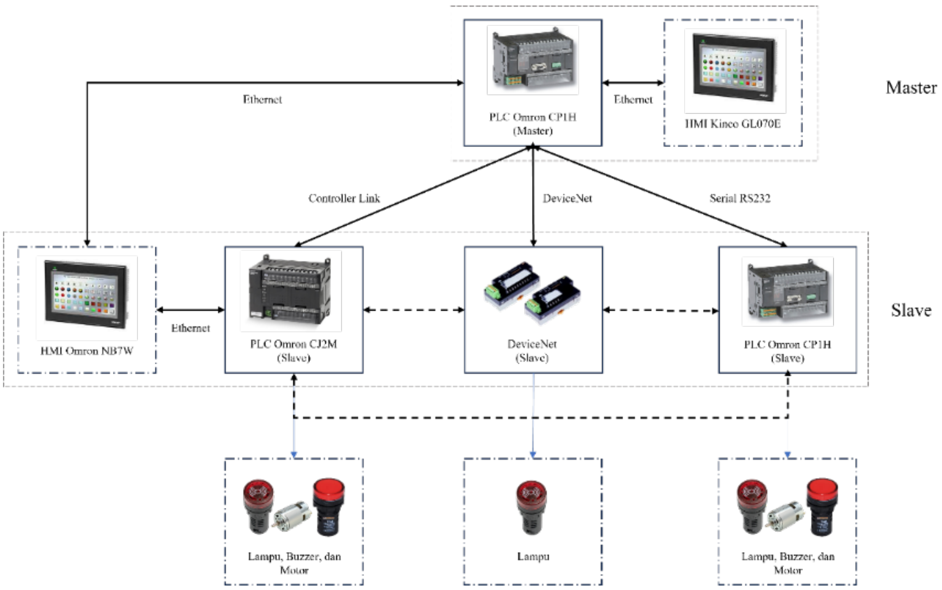

Figure 2. System Overview

Figure 2 is a system overview of the design that has been made. This system overview describes the relationship between system components in general. There are components in the system. Programmable Logic Controller or PLC Master can communicate with all Slave devices, and vice versa. PLC and fellow Slave devices can communicate through the PLC Master. The communication protocols used are Serial RS-232C, DeviceNet, and Controller Link (FINS). Human Machine Interface or HMI Master can communicate with all Slave devices, then HMI Slave can communicate with fellow Slave devices and PLC Master via Ethernet communication (TCP/IP). PLC outputs such as lights, buzzers, and DC motors are used for testing indicators of the communication network between PLC and HMI.

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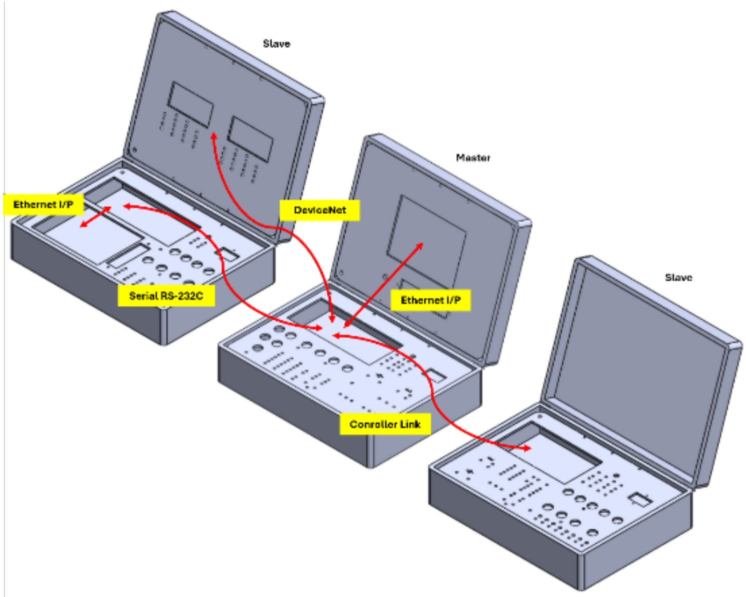

Figure 3. Mechanical Design of The Trainer Tools

Figure 3 is a mechanical design on this trainer tool. The media used in this trainer tool uses a box on the plant from the KRISBOW brand which is widely known in Indonesia and several other Asian countries, famous for industrial products and engineering tools. The dimensions of the box are 46x13x15 cm. This box uses Aluminum material which is certainly corrosion resistant and high strength. In addition, the media on the placement of components uses acrylic material with a thickness of 5mm.

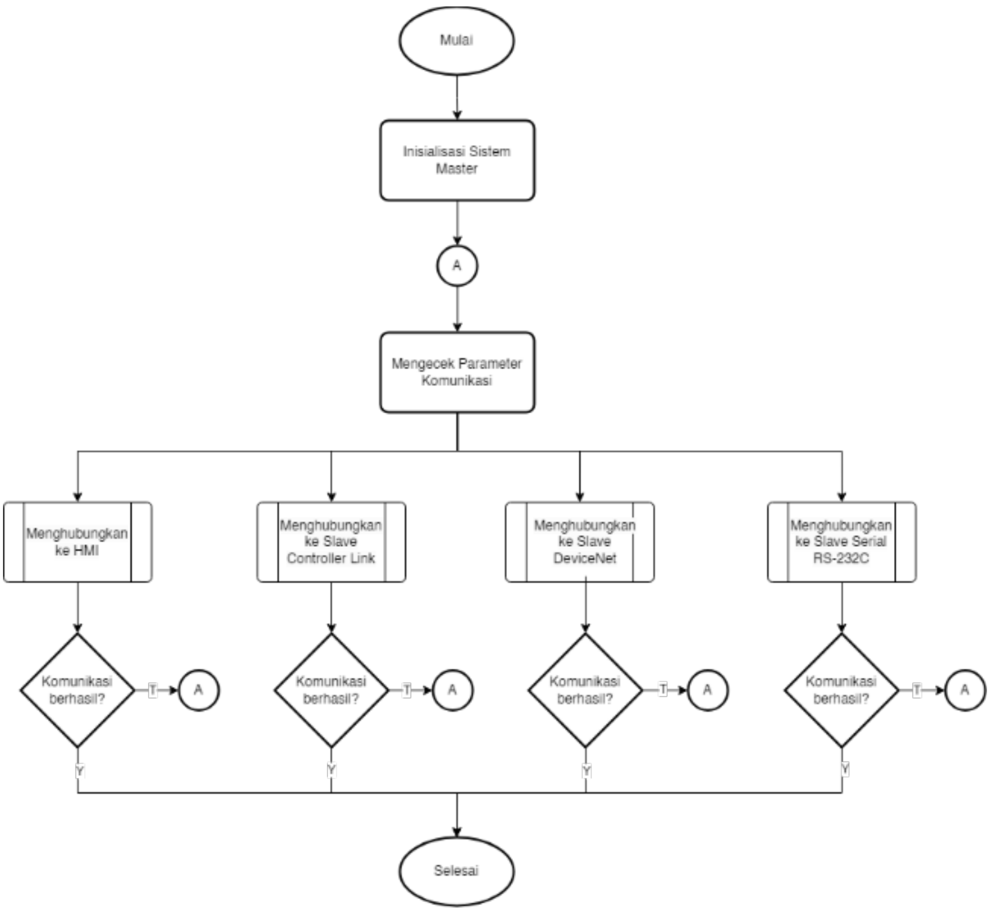

Figure 4. System Flow Diagram

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Figure 4 explains how the master-slave PLC communication network system works. It begins with the master system checking the connections and communication parameters connected to the slave and HMI networks. After initializing, the master PLC connects the connection to each slave device and HMI. 4 types of communication protocols are used in this system. Then, the slave device and HMI respond to the requested communication, if the parameters and configuration match the PLC master, then the communication is successfully connected, otherwise the PLC master will re-initialize repeatedly to request the appropriate communication parameters on the slave network and HMI. Testing on the PLC program can be done after the master-slave communication is connected, if an error occurs, the master will disconnect the slave.

Software Design

The software design aims to create an interface to this trainer tool plant. Figure 5 is a design view on the HMI Master Kinco GL070E interface.

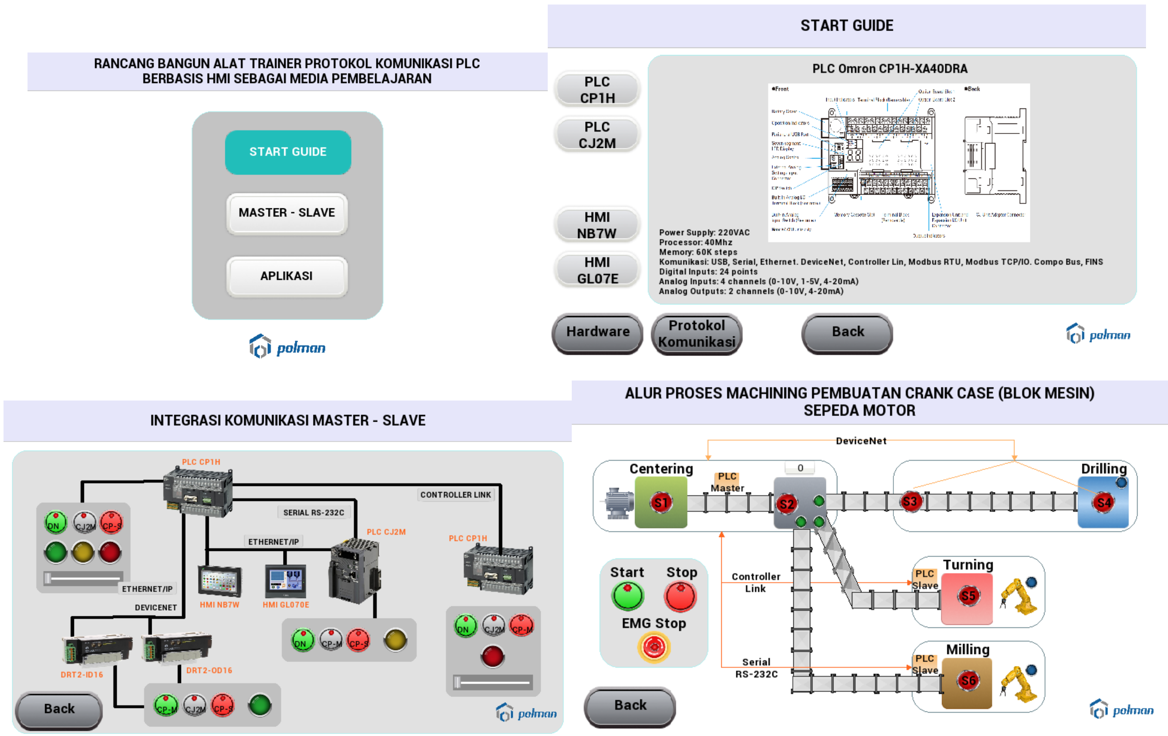

Figure 5. HMI Interface Display

This interface is divided into 3 main sections. In the “Start Guide” section, the basic theory and information about the hardware, software, and communication protocols used are explained. Then, the “Master-Slave” section displays the display of the integration system in the three suitcases or plants. This section also displays a push button on the HMI to validate the communication that has been designed. Later users can communicate between PLC and HMI using this push button. So, users can find out how the communication process works from this trainer tool and get an attractive visual display of the HMI in this Master-Slave section. Furthermore, the “Application” section shows a simple application of the communication protocol integration of this trainer. In the application, it is made simply and takes the theme of the production process in the manufacturing industry

Results and Discussion

Hardware Implementation

The results that have been achieved in this system design consist of the integration of mechanical, electrical, and informatics parts. The resulting implementation is in the form of

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3 media boxes consisting of 3 PLCs, including Omron CP1H master PLC, Omron CP1H slave PLC, and Omron CJ2M slave PLC. In addition, there are 2 media interface screens used, namely the Kinco GL070E HMI as the master interface screen and the NB7W HMI as the slave interface screen. Then 3 types of communication protocols are used to communicate between PLCs, namely Controller Link used by Omron CP1H master PLC communicating with Omron CP1H slave PLC using CJ1W-CLK21 communication module. DeviceNet is used by the master Omron CP1H PLC with the CJ1W-DRM21 communication module to communicate with sensors and actuators that are far apart on the DRT2-ID16 and DRT2-OD16 modules. Serial RS-232C is used to communicate the master Omron CP1H PLC with the Omron CJ2M PLC as a slave using the CP1W-CIF01 communication module. Figure 6 is the result of the implementation of hardware design consisting of the integration of mechanical, electrical, and informatics design.

Figure 6. Hardware Implementation Results

The implementation results of the mechanical design include a media box design and an acrylic layout design as a place to store the components used in this system. In the acrylic layout design, the names and descriptions of the components used are also written so that users can find out the specifications of these components. The implementation results of the electrical design include the design of 220V AC power / electric current, 24VDC electric current, electric current in PLC, HMI, banana jack, sensors, lights, motors, and design on the Controller Link communication protocol wiring, DeviceNet, Serial RS-232C, and Ethernet. The implementation results of the informatics design include PLC program design, HMI program, PLC communication protocol program, and integration of PLC, HMI, and communication protocol programs.

DeviceNet Communication Protocol Testing

Testing the DeviceNet communication protocol is to integrate the Omron CP1H master PLC address/address to the DeviceNet slave. This test will focus on the latency of the DeviceNet communication network on digital values. This test involves between the CJ1W-DRM21 master module on the CP1H master PLC and the DRT2-OD16 slave devices as output modules and DRT2-ID16 as input modules.

Table 1. DeviceNet communication protocol testing baud rate 100 Kbps

No.	*Baud rate*	CP1H *Master* (*time start*)	*Slave* DRT2 (*time finish*)	*Delay* (ms)
1	100 Kbps	10:01:52:573	10:01:52:589	16
2		10:02:25:125	10:02:25:140	15
3		10:04:63:772	10:04:63:789	17
4		10:05:17:084	10:05:17:099	15
5		10:07:41:615	10:07:41:633	18
			Average:	**16**

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Table 1 is the result of testing the DeviceNet communication protocol at a baud rate of 100 Kbps. From the data, the average delay time for DeviceNet communication at a baud rate of 100 Kbps is 16 ms.

Controller Link Communication Protocol Testing

Testing the Controller Link communication protocol is to integrate the Omron CP1H master PLC address/address to the Omron CP1H slave PLC. This test will focus on the latency of the Controller Link communication network on digital values. This test involves between the CJ1W-CLK21 master module on the CP1H master PLC and the CJ1W-CLK21 slave module on the other CP1H slave PLC.

Table 2. Controller Link communication protocol testing baud rate 500 Kbps

No.	***Baud rate***	**CP1H *Master* (*time start*)**	**CP1H *Slave* (*time finish*)**	***Delay* (ms)**
1	500 Kbps	08:50:11:124	08:50:11:133	9
2		08:51:24:343	08:51:24:353	10
3		08:52:41:505	08:52:41:513	8
4		08:53:37:234	08:53:24:243	9
5		08:54:24:489	08:54:24:498	9
			Average:	**9**

Table 2 is the result of testing the Controller Link communication protocol at a baud rate of 500 Kbps. From the data, the average delay time on Controller Link communication baud rate 500 Kbps is 9 ms.

Table 3. Pengujian protokol komunikasi Controller Link baud rate 1 Mbps

No.	***Baud rate***	**CP1H *Master* (*time start*)**	**CP1H *Slave* (*time finish*)**	***Delay* (ms)**
1	1 Mbps	09:00:22:410	09:00:22:416	6
2		09:01:32:164	09:01:32:171	7
3		09:02:56:785	09:02:56:791	6
4		09:04:23:854	09:04:23:860	6
5		09:05:42:375	09:05:42:380	5
			Average:	**6**

Table 3 is the result of testing the Controller Link communication protocol at a baud rate of 1 Mbps. From the data, the average delay time on Controller Link communication baud rate 1 Mbps is 6 ms.

Table 4. Controller Link communication protocol testing baud rate 2 Mbps

No.	***Baud rate***	**CP1H *Master* (*time start*)**	**CP1H *Slave* (*time finish*)**	***Delay* (ms)**
1	2 Mbps	09:10:43:864	09:10:43:868	4
2		09:11:13:026	09:11:13:031	5
3		09:12:53:297	09:12:54:201	4
4		09:13:41:743	09:13:41:747	4
5		09:14:39:675	09:14:39:678	3
			Average:	**4**

Table 4 is the result of testing the Controller Link communication protocol at a baud rate of 2 Mbps. From these data, the average delay time on Controller Link communication baud rate of 2 Mbps is 4 ms.

RS-232C Serial Communication Protocol Testing

Testing the RS-232C Serial communication protocol is to integrate the Omron CP1H master PLC address/address to the Omron CJ2M slave PLC. This test will focus on the latency of the

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RS-232C Serial communication network on digital values. This test involves the CP1H master PLC and the CJ2M-CPU34 slave PLC with the CP1W-CIF01 communication module.

Table 5. Serial RS-232C communication protocol testing baud rate 38.4 Kbps

No.	*Baud rate*	CP1H *Master* (*time start*)	CJ2M *Slave* (*time finish*)	*Delay* (ms)
1	38,4 Kbps	10:33:52:663	10:33:52:691	28
2		10:34:45:210	10:34:45:241	31
3		10:34:22:762	10:34:22:789	27
4		10:35:50:583	10:35:50:611	28
5		10:36:38:518	10:36:38:547	29
			Average:	**29**

Table 5 is the result of testing the RS-232C Serial communication protocol at a baud rate of 38.4 Kbps. From the data, the average delay time on Serial RS-232C baud rate 38.4 Kbps communication is 29 ms.

Table 6. Serial RS-232C communication protocol testing baud rate 115.2 Kbps

No.	*Baud rate*	CP1H *Master* (*time start*)	CJ2M *Slave* (*time finish*)	*Delay* (ms)
1	115,2 Kbps	10:38:53:635	10:38:53:647	12
2		10:39:15:744	10:39:15:757	13
3		10:39:52:360	10:39:52:372	12
4		10:40:25:629	10:40:25:640	11
5		10:41:42:953	10:41:42:965	12
			Average:	**12**

Table 6 is the result of testing the RS-232C Serial communication protocol at a baud rate of 115.2 Kbps. From the data, the average time delay on Serial RS-232C baud rate 115.2 Kbps communication is 12 ms.

Ethernet Communication Protocol Testing

The following is a protocol test on Ethernet communication. This test is used to test the network connectivity between the computer and HMI device with IP address 192.168.250.4. The PING command sends an ICMP Echo Request packet to the specified IP address and waits for an ICMP Echo Reply. The results provide information on whether the device is reachable as well as the time taken for the data to travel to the device and back as shown in Table 7.

Table 7. Testing communication protocols on Ethernet

No.	*Baud rate*	Data Size (byte)	TTL	*Respons Time* (ms)
1	10 Mbps	32	64	2,00
2		32	64	3,00
3		32	64	3,00
4		32	64	3,00
Average:				**2,75**
Number of data sent:				**4**
Number of data received:				**4**

From the data, the average response time of the communication protocol on Ethernet is 2.75 ms. The amount of data sent matches the amount of data received indicating no packet loss, which means the connection is stable and reliable.

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Pedagogical Aspect Testing Interface

Testing the pedagogical aspects of this interface intends to include assessments that will be made to evaluate the results of the work that has been done. In this research, the EMPI method is used for user evaluation testing. In this method, participation of at least 10% of the entire population of the target environment of respondents is required so that the assessment is considered valid (Castrena et al., 2023). The purpose of conducting an evaluation with a questionnaire system using the EMPI method is to measure aspects of interface quality related to the learning media that has been created. The assessment was made by involving 12 respondents from a total population of 96 people consisting of 3rd year students of the Manufacturing Automation and Mechatronics Engineering Department at Politeknik Manufaktur Bandung or POLMAN Bandung. The evaluation was conducted based on six criteria, namely: a) General Feeling: Assesses the overall teaching aid; b) Computer Science Quality: Assess the technical quality of the interface creation; c) Usability: Assessing the ease of use of teaching aids in terms of ergonomics; d) Multimedia Documents: Assess the quality of multimedia components in teaching aids; e) Scenario: Assess the menu navigation structure of the interface; f) Didactical: Assessing the educational design and teaching methods applied in the teaching aids.

This questionnaire uses a Likert scale for scoring, with weights divided into 5 categories, as follows:

Weight 5 - Very Good

Weight 4 - Good

Weight 3 - Fair

Weight 2 - Less Good

Weight 1 - Very Not Good

These results are then entered into the following equation to calculate the overall final score.

$$value = \frac{\sum_{i}^{number\ of\ respondents} weight\ of\ respondents\ i}{number\ of\ respondents\ x\ 5} x100\%$$

The formula calculates the value based on the weight of each respondent, which is then divided by the number of respondents multiplied by 5 (Likert maximum scale), then multiplied by 100% to get the value in percentage. The following are the results of the overall value of the evaluation and assessment of trainer tools by 12 respondents in the Department of Teknik Otomasi Manufaktur dan Mekatronika POLMAN Bandung.

Table 8. Overall interface assessment results

No.	Rated Aspect	Average Rating (Scale)	Value (%)
1	General Feeling	4,8	96,6
2	Computer Science Quality	4,7	94,2
3	Usability	4,8	95
4	Multimedia Documents	4,6	92,5
5	Scenario	4,8	95
6	Didactical	4,9	97,5
Total Value			**95,1**

Table 98 shows the overall score obtained from the research results. The highest score is in the “Teaching Structure and Comprehensibility” assessment aspect with a score of 97.5%. Meanwhile, the lowest value is in the “Multimedia Document” assessment aspect with a value of 92.5%. With an average total score of 95.1%, this assessment produces a very good score

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so that the communication protocol trainer tool on the network between PLC and HMI is a learning tool that supports the learning process.

Conclusion

Based on the research that has been done, it can be concluded that the manufacture of PLC communication protocol trainer tools using 3 communication protocols, namely Controller Link, DeviceNet, and Serial RS-232C is successfully integrated with 1 system and connected to HMI as an interface screen via Ethernet communication.

Controller Link communication tests with baud rates of 500 Kbps, 1 Mbps, and 2 Mbps get an average delay time of 9 ms, 6 ms, and 4 ms. DeviceNet communication testing with a baud rate of 100 Kbps gets an average delay time of 16 ms. RS-232C Serial communication testing with a baud rate of 38.4 Kbps and 115.2 Kbps gets an average delay time of 29 ms, and 12 ms.

Based on the assessment results, overall the evaluated trainer received a high score of 95.1% from 6 assessment aspects, namely General Impression, Technical Quality of Interface, Usability and Ergonomics, Multimedia Documents, Interface Scenarios, and Teaching Structure-Comprehension. This value indicates that the teaching aid is considered as a tool that facilitates and is effective in assisting the teaching and learning process of students.

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