Jurnal Teknologi Bahan dan Barang Teknik
Vol. 11, No. 1, Juni 2021: 1-14
e-ISSN: 2715-9116
DOI: 10.37209/jtbbt.v11i1

PLC-BASED SIMULATOR TO CONTROL THE ROAD TRAFFIC THROUGH OPERATING THE ANALOGOUS OF BRIDGE BODIES ON TWO WATER CANALS FOR THE SHIP-PATH SYSTEM

SIMULATOR BERBASIS PLC UNTUK KONTROL LALU-LINTAS JALAN RAYA MELALUI PENGOPERASIAN ANALOGI BADAN JEMBATAN PADA DUA KANAL AIR SEBAGAI SISTEM PERLINTASAN JALUR KAPAL

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Diterima: 5 Januari 2021 Direvisi: 10 Februari 2021 Disetujui: 4 Maret 2021

ABSTRAK

Inti penelitian ini berkaitan dengan rancang-ulang untuk ketercapaian simulator berbasis sistem tertanam secara umum dan pemanfaatan seperangkat pengontrol logika terprogram (programmable logic controllers, PLC) secara khusus. Penelitian ini dengan penggunaan sistem instrumentasi dan mekanisme otomasi terkontrol oleh PLC yang berfungsi sebagai simulator untuk pengoperasian analogi badan jembatan ganda untuk jalur lalu-lintas jalan, yaitu jalan raya di persimpangan dengan saluran air ganda sebagai sistem jalur kapal atau penyeberangan kapal. Beberapa hasil meliputi (i) prinsip pengoperasian simulator, diamati sensor-sensor terpasang pada simulator, apakah berfungsi sesuai yang diprogramkan dalam PLC; (ii) apabila mode auto pengangkatan badan jembatan, baik pada badan jembatan #1 maupun #2, lebih lama dari proses penurunan badan jembatan, maka lebih ditekankan pada adanya gaya gravitasi; dan (iii) tidak ada perbedaan waktu yang signifikan dibandingkan antara pemilihan mode otomatis dan manual. Kesimpulan berdasarkan empat sasaran penelitian utama dan topik yang dilakukan, bahwa tahapan untuk pengukuran kinerja simulator berbantuan PLC dan digerakkan oleh GX Work Mitsubishi dapat diwujudkan sesuai dengan ide awal dan rancangan untuk pemilihan dan penentuan perangkat keras dan lunak.

Kata kunci: simulator berbasis PLC, pengoperasian lalu-lintas jalan raya, analogi badan jembatan, dua kanal air, sistem jalur kapal.

ABSTRACT

The essence of this research relates to the redesign for the acquisition of a simulator based on an embedded system in general and specifically to the utilization of a set of programmable logic controllers (PLCs). The research was chosen on the use of instrumentation systems and controlled automation mechanisms by a PLC which functioned as a simulator to operate the double bridge bodies analogy for road traffic lanes, i.e., highways on crossings with dual water canals as the ship-path system or ship crossings. Some results are (i) the operating principle of the simulator, it is observed for the sensors installed on the simulator, whether they are functioning as programmed into the PLC; (ii) when the auto mode of lifting the bridge body, both on bridge bodies #1 and #2, is longer than the process of lowering the bridge bodies, it is more emphasized on the existence of a gravitational force; and (iii) there is no significant time difference compared between the auto and manual mode selection. Concluding based on the four main research objectives and topics carried out that the stages for performing the simulator assisted by PLC and driven by GX Work of Mitsubishi can be realized according to the initials of idea and design for selecting and determining the hardware and software.

Keywords: PLC-based simulator, road traffic operation, analogous of the bridge bodies, two water canals, ship-path system

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DOI: http://dx.doi.org/10.37209/jtbbt.v11i1.262

PENDAHULUAN

This research is motivated by a special reference to previous studies related to simulators for the analogy of regulating highway traffic at ship lane crossings [1]. The essence of this research relates to the redesign for the acquisition of a simulator based on an embedded system [2-5] in general and specifically to the utilization of a set of programmable logic controllers (PLCs) [6-9]. The PLC system still functions as the center of control for a simulator, while the sensor-transducer and actuator systems are changed, because the analogy of the bridge body has also changed, from one become two. Based on the addition of the number of analogous bridge bodies, some sensor-transducer systems, and several actuators driver systems were also added. According to the explanation of the reason for choosing the title, a number of previous state-of-the-art and closely related to this research become special references, especially the selection of the PLC for branding and typing, and type of sensor-transducer system, as well as actuator driver system.

Previous state-of-the-art includes several PLC-based simulators for specific purposes or as a specific system, including for operating the system of material sorting mechanism [10], the rejection system [11], the bottle filling and cap installation, as well as simulators for operating the bottle labelling and separation systems [12, 13]. Based on this description, the role of PLC as controlling device for simple automation mechanisms against a number of electronic instrumentation devices [14-18] which is equipped with a computer program syntax structure has been made [19-22]. The syntax structure is a built program or user program.

The fabricated simulator in the previous study was a prototype embedded device based on an instrumentation and automation system [1]. The prototype is assisted by a set of Mitsubishi PLC type FX0N-24RM [23, 24] with a number of sensor-transducer systems connected to the input ports, and several actuator controllers are connected to the output ports [25, 10-18]. There are some shortcomings in previous research with guidelines and procedures needed for improvement and development efforts [18], so these guidelines and procedures are the main concern in carrying out this research [26, 27].

The comparison between previous and current research is shown in Figure 1.

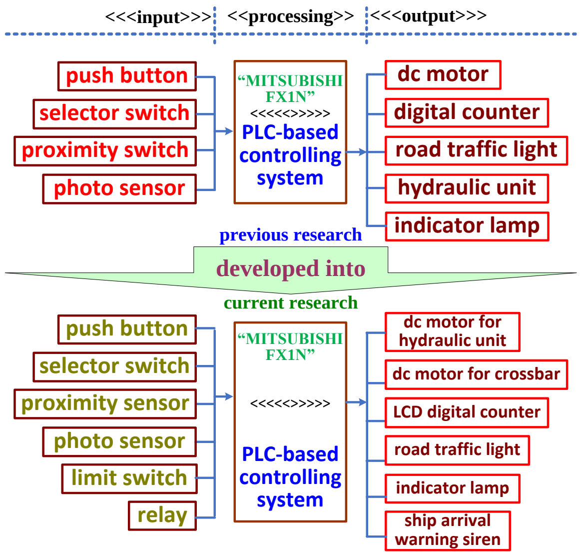

Figure 1. The comparison between Previous and Current Research

Based on those descriptions, a problem formulation related to the research topic was chosen on the use of instrumentation systems and controlled automation mechanisms by a PLC [10-13] which functioned as a simulator for the operation of a double bridge bodies analogy for traffic lanes, highways on crossings with dual water canals for ship crossings, which in the previous study only consisted of one water canal for ship-path [1]. The structure and layout of previous and current research is a description of a research development that can be realized in the form of a problem formulation.

The prototype of the controller system based on the Mitsubishi PLC type of FX1N was developed to operate the actuator on the bridge opening and closing system assisted by a hydraulic system for the lifting mechanism (Figure 2). The system for opening and closing the bridge bodies has been completed with a detection control system for more than one ship from both directions automatically, analogies of road traffic and ship-path. The development in the form of (i) addition to two sides of the bridge body, (ii) automation of bridge lifting based on the direction of ship arrival without the use of additional switches, (iii) making a system for counting the number of ships passing by using a digital counter system, and (iv) adding warning sirens as an additional safety system.

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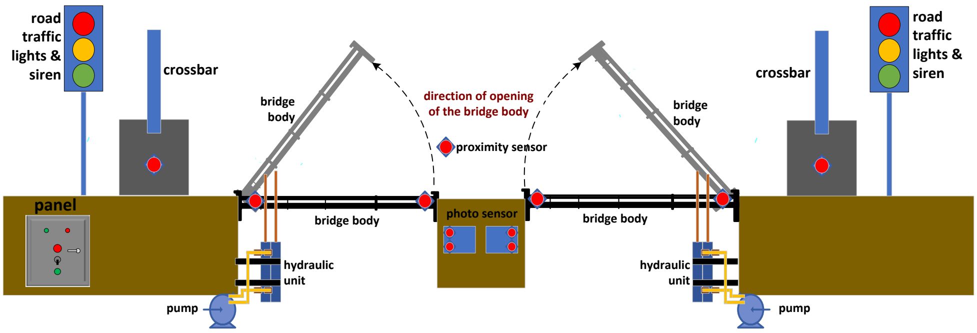

Figure 2. A Schematic Diagram for Formulating the Problem

The research development, in this study the four The research objectives are (i) to manufacture the main mechanical frame structure and assembling the parts of the physical miniature bridge bodies, (ii) to integrate of the all components of electronic modules and the support system through wiring mechanism of the embedded system, (iii) to make a program structure based on ladder diagram software as a built application for the PLC-based simulator, and (iv) to perform the simulator based on PLC for operating the bridge bodies analogy when opening or closing.

METHODS OF RESEARCH

Some stages must be carried out sequentially the research objectives so the research methods are made (i) in the form of a flow chart and (ii) under steps for achieving each research objective [28, 29]. The existence of a research method is a form of algorithm in the implementation of each step of the research carried out by a researcher, as shown in Figure 3. The research methods consisted of several steps to carry out each research objective (Figure 3).

RESULTS AND DISCUSSION

Physical of the Bridge Bodies Analogy

The physical form of a PLC-based simulator for operating the analogous of bridge bodies when opened or closed is carried out by manufacturing the physical of the bridge bodies analogy, hydraulic systems, and crossbar mechanism. Installation of a hydraulic system in the development of a miniature bridge frame is shown in Figure 4.

A number of components for the development of a miniature bridge consist of (i) hydraulic cylinders, (ii) dc motors driving the hydraulic system mechanism, (iii) counters to count the number of ships passing by, (iv) warning sirens, (v) limit switches up/down bridges. (vi) sensors. The mounted hydraulic cylinder is made of compressed fluid injection. The motor used is a dc motor type, on the motor there are 4 mm threads and bolts for injection propulsion, so that the hydraulic system operates and the body can be lifted.

The sensors are mounted on the miniature frame of the bridge body, namely (a) proximity sensor, (b) “autonic” photo sensor, and (c) limit switch. Installation of the prototype parts of the simulator for opening or closing the bridge bodies are shown in Figure 5.

The position of the motor for the hydraulic system is inside the bridge miniature physical frame and the hydraulic cylinder is under the bridge miniature frame. The position of the crossbar-stop is at the end of the miniature road on both sides of the bridge body, where in the crossbar-stop system there is a proximity sensor with a function as an indicator of the presence of the vehicle, so as not to be crushed by the crossbar-stop when closing. A traffic light with a function as a traffic control device and an indicator when a ship crosses the path where the bridge body is lifted. The existence of “autonic” photo sensor reader ship #1 for readings when there is a passing ship, “autonic” photo sensor reader ship #2 for reading when the ship has passed the bridge and the bridge is closed again. The “autonic” photo sensor above the miniature bridge body, serves as an indicator of the presence of vehicles that are still above the miniature bridge body, so that the miniature bridge body is not lifted until the condition of the miniature bridge bodies is empty from the vehicle.

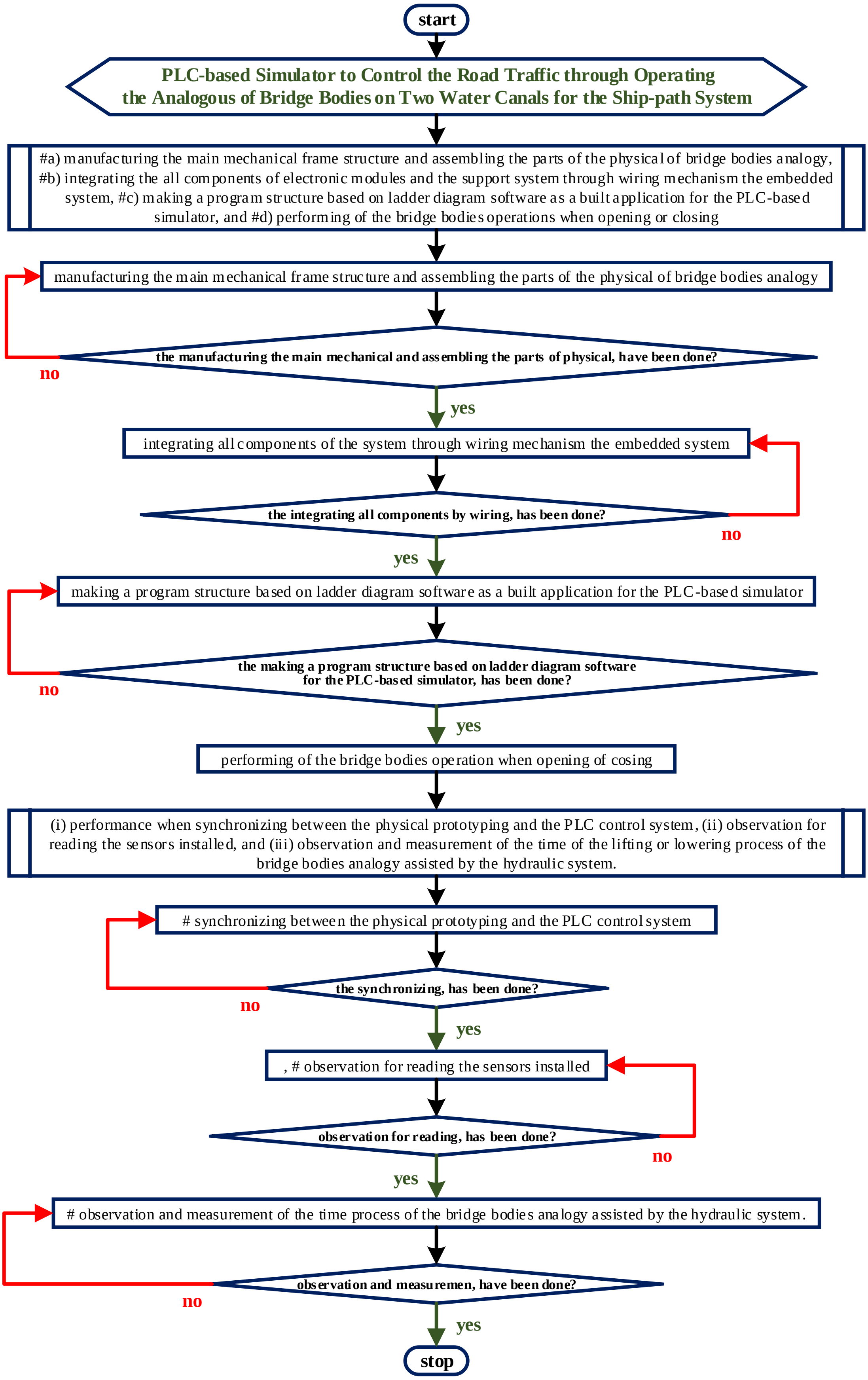

Figure 3. A Form of the Flowchart as an Integral Part of the Research Methods

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Figure 4. Installation of a Hydraulic System in the Development of a Miniature Bridge Frame

Integration of All Components of Electronic Modules and the Support System through Wiring Mechanism for an Embedded System

Addressing the input and output on the PLC must be determined to facilitate the programming and wiring process. Addressing input and output on the Mitsubishi PLC system with type of FX1N-60MT is shown in Table 1.

All components operate integrated with each other in the control system. Installation of a number of components in the controller subsystem is shown in Figure 6.

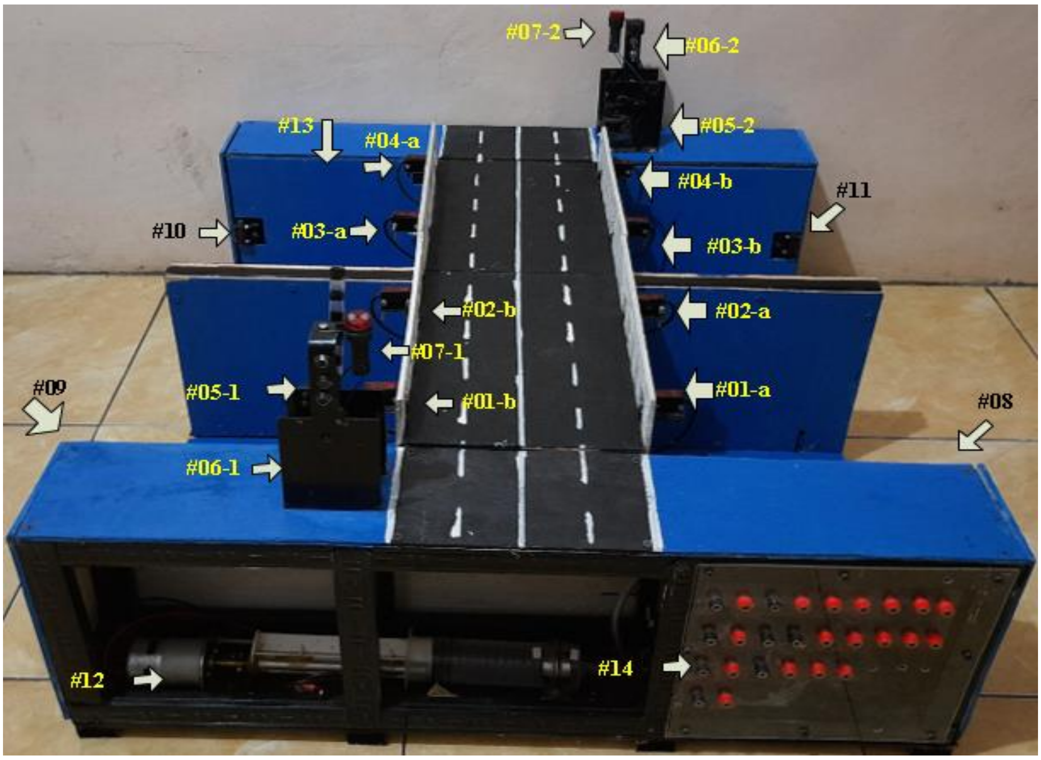

Figure 5. Installation of the Prototype Parts of the Simulator for Opening or Closing the Bridge Bodies

Notes:

#01-a: Autonics photo sensor as a transmitter for bridge body-1 (vehicle)
#01-b: Autonics photo sensor as a receiver for bridge body-1 (vehicle)
#02-a: Autonics photo sensor as a transmitter for bridge body -1 (vehicle)
#02-b: Autonics photo sensor a receiver for bridge body-1 (vehicle)
#03-a: Autonics photo sensor as a transmitter for bridge body-2 (vehicle)
#03-b: Autonics photo sensor as a receiver for bridge body-2 (vehicle)
#04-a: Autonics photo sensor as a transmitter for bridge body-2 (vehicle)
#04-b: Autonics photo sensor as a receiver for bridge body-2 (vehicle)
#05-1: Crossbar-stop driver assisted by servo motor #1
#05-2: Crossbar-stop driver assisted by servo motor #2
#06-1: Road traffic light #1
#06-2: Road traffic light #2
#07-1: Warning siren #1
#07-2: Warning siren #2
#08: Omron photo sensor for bridge body-1 (ship entry)
#09: Omron photo sensor for bridge body-1 (ship out)
#10: Omron photo sensor bridge body -2 (ship out)
#11: Omron photo sensor bridge body -2 (ship entry)
#12: Motor and hydraulic cylinder for lifting the bridge body-1
#13: Motor and hydraulic cylinder for lifting the bridge body 2
#14: Terminals for wiring to PLC system

Table 1. Addressing Input and Output on the Mitsubishi PLC FX1N-60MT

Input		Output	
Address in PLC	**Address in the physical simulator**	**Address in PLC**	**Address in the physical simulator**
X000	Emergency stop	Y000	R1
X001	Auto Mode	Y001	R2
X002	Manual Mode	Y002	R3
X003	Push Button; “UP”; BB#1	Y003	R4
X004	Push Button; “DOWN”; BB#1	Y004	R5
X005	Push Button; “UP”; BB#2	Y005	R6
X006	Push Button; “DOWN”; BB#2	Y006	R7
X007	Photo Sensor; Ship-path#1; BB#1	Y007	R8
X010	Photo Sensor; Ship-path#2; BB#1	Y010	R9
X011	Photo Sensor; Ship-path#1; BB#2	Y011	R10
X012	Photo Sensor; Ship-path#2; BB#2	Y012	R11
X013	Photo Sensor for Vehicle; BB#1	Y013	Counter-1
X015	Photo Sensor for Vehicle; BB#2	Y014	Counter-2
X017	Limit Switch; BB#1; “UP”	Y015	Reset Counter-1
X020	Limit Switch; BB#1; “DOWN”	Y016	Reset Counter-2
X021	Limit Switch; BB#2; “UP”	Y017	Siren
X022	Limit Switch; BB#2; “DOWN”		
X023	Proximity Sensor for the crossbar #1		
X024	Proximity Sensor for the crossbar #2		

Figure 6. Installation of a number of components in the controller subsystem

As shown in Figure 6, the components in the controller subsystem, namely (i) Mitsubishi PLC module type of FX0N-24MR, (ii) switched-mode power supply 24 V-dc, 3A, (iii) buck converter 12 V-dc, (iv) MCB 2A, (v) a circuit of dc voltage regulator, (vi) a number of relays with a coil of 24 V-dc, (vii) an emergency stop push button, (viii) a push button, and (ix) a selector switch. These components are arranged and integrated wiring is carried out on a panel box with the dimension of 40 cm x 50 cm x 20 cm.

A physical cross-section of the panel box and connecting terminals is shown in Figure 7. There are two power supply lines, namely the 220 V-ac and 24 V-dc. Input and output on the PLC used a red cable operating with a voltage of 24 V-dc marked with different cable shoes for the positive and negative poles. The 220 V-ac power supply is connected to the MCB 2 A.

Figure 7. A physical cross-section of the panel box and connecting terminals

Miniature Circuit Breaker is an important factor in a circuit with an integrated system, i.e., as a protection system in the circuit to prevent component damage when a short circuit occurs. The 24 V-dc power supply is used to supply a voltage source to the controller system. The output voltage of the switched-mode power supply is relatively stable, so it is suitable for controlling PLC-based systems. Voltage stability is very influential on the performance of the PLC. The PLC I/O line operates at a maximum stable control voltage of 24 V-dc.

A connection of the wiring diagram to the ports of input and output are shown in Figure 8. The development of the wiring of the components in the bridge bodies analogy when open/close system begins with connecting an ac voltage source to the MCB, the MCB output is connected to the power supply input for the PLC via a switched mode power supply. The output of the 24 V-dc switched-mode power supply (positive pole) is connected to the relay coils R1, R2, R4, R5, R6, R7, R8, R9, R10, and R11 including to the sensors, and to the input lines of the voltage regulator circuit, while the output of the voltage regulator circuit is connected to the auxiliary contact NO on relays R1, R2, R4, R5, R6, R7, R8, R9, R10, and R11 as a power supply line for the hydraulic cylinder driving motor, doorstop, and traffic light.

All PLC inputs and outputs are NPN, which means that all inputs to the PLC are

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common negative and PLC outputs are also common negative. The input ports on the open-close system include (i) emergency stop ON, (ii) auto/manual selector switch, (iii) UP bridge push button, (iv) DOWN bridge push button, and (v) sensors with all input line is connected common negative N24 (24 V-dc power supply, negative pole). The output port on the PLC module is connected to the negative pole of the relay coil R1, R2, R4, R5, R6, R7, R8, R9, R10, and R11.

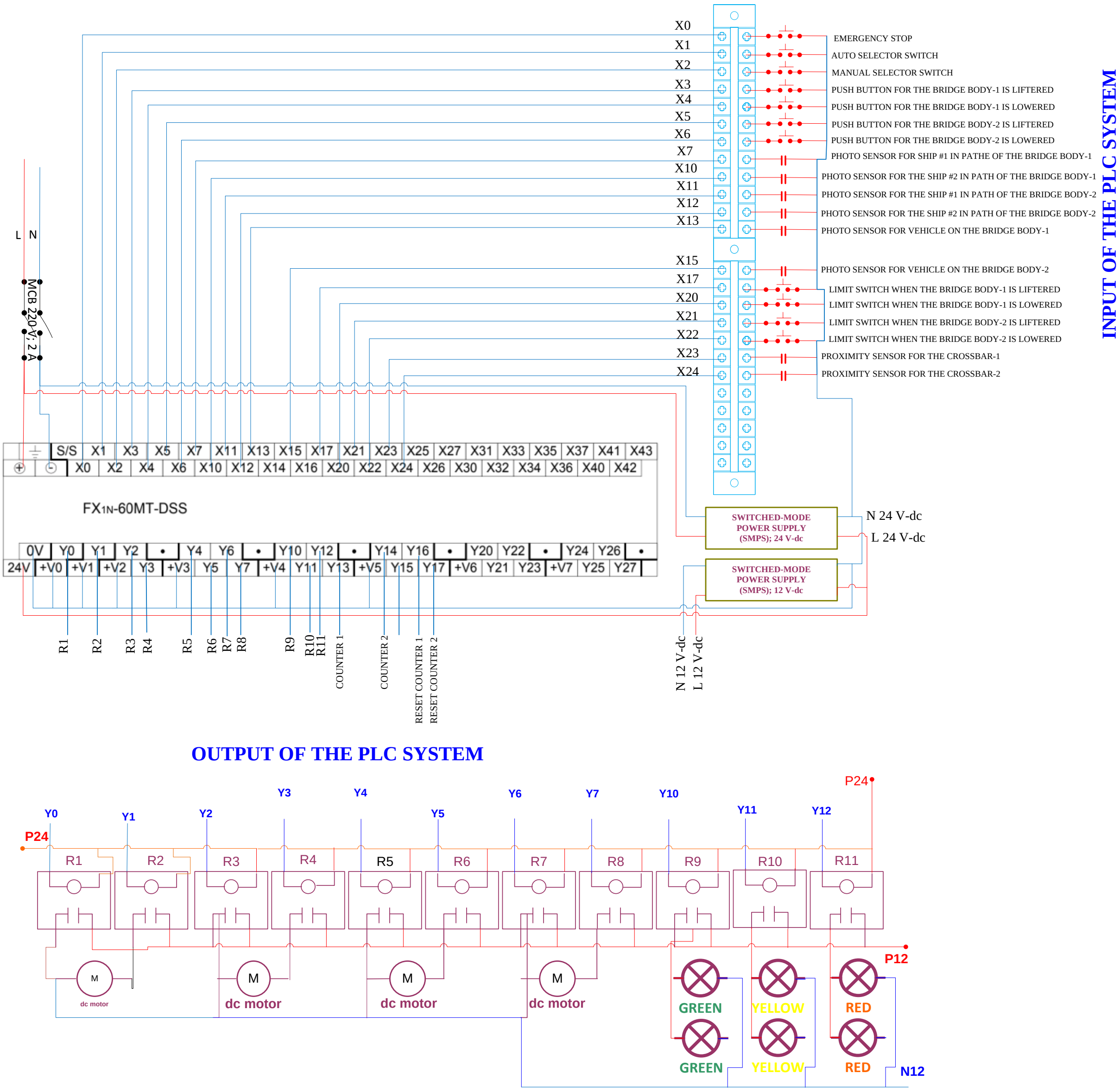

Figure 8. A Connection of the Wiring Diagram to the Ports of Input and Output

The circuit and components of each system for the realization of a miniature bridge bodies as a prototype system based on Mitsubishi PLC, it is necessary to assemble and integrate. The prototype of the PLC-based miniature bridge body open-close system is connected to a terminal box with a female jack socket installed and connected to the control panel. The development of a simulator prototype of a miniature bridge body open-close system is divided into 2 parts, namely the mechanism block and the control block. The integration of the prototype is done by wiring and the use of banana jack type female socket. Integration of the prototype is shown in Figure 9.

Figure 9. Integration of the Prototype

A Built Program Structure Based on Ladder Diagram

The PLC system programming is based on algorithm and syntax structure. The algorithm is determined and based on a flow chart, while the syntax structure is built according to a standard of Mitsubishi PLC system, i.e., ladders with GX Developer/GX Work. The programming algorithm for opening or closing mechanism of the bridge bodies analogy is shown in Figure 10.

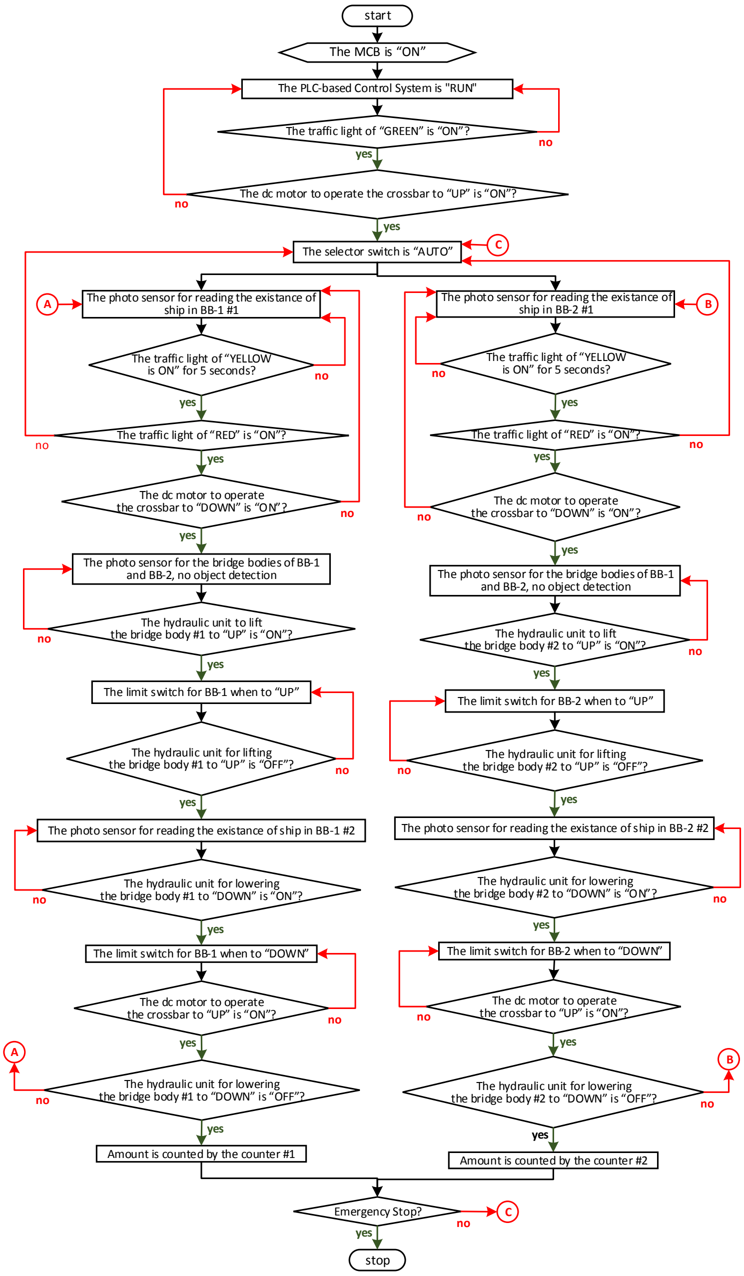

Figure 10. The Programming Algorithm for Opening or Closing Mechanism of the Bridge Bodies Analogy

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Based on the algorithn presented in Figure 10, the ladder for PLC programming was carried out. The ladder diagram arrangement display is shown in Figure 11.

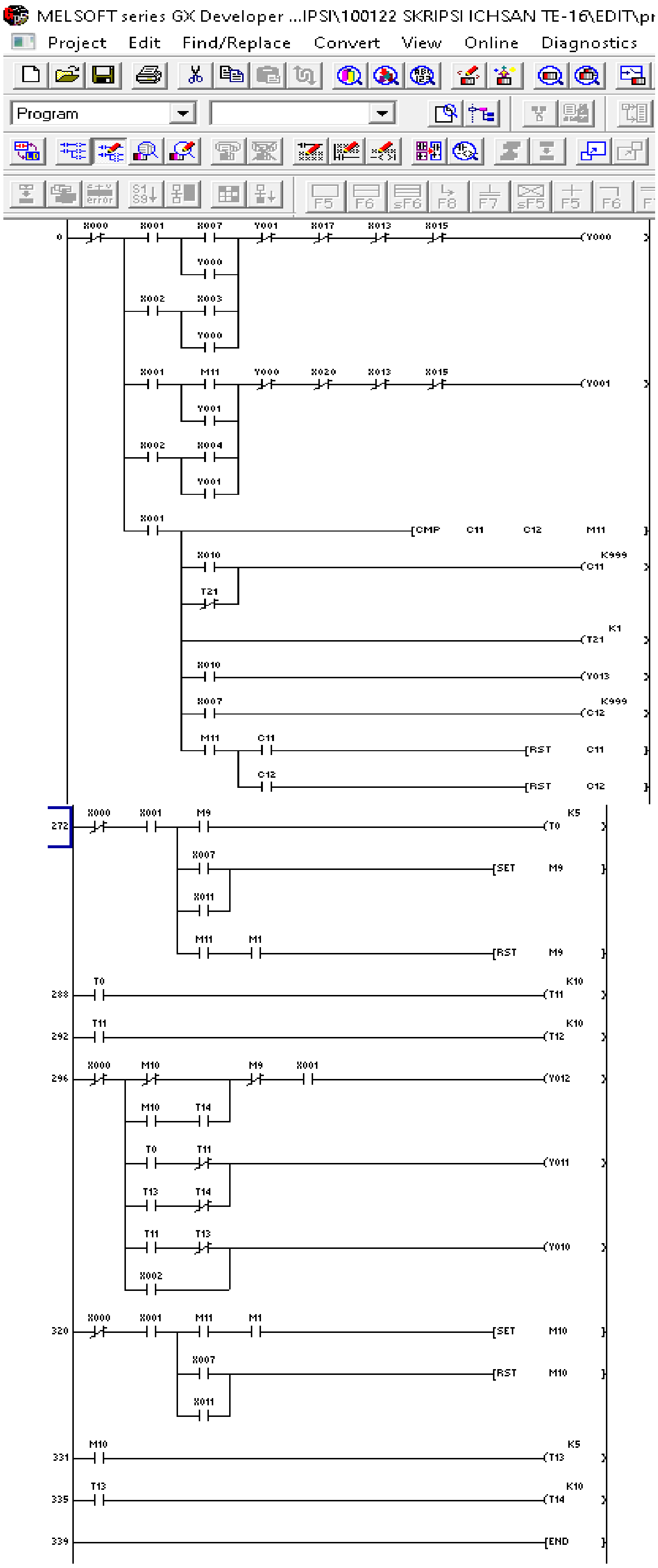

Figure 11. The Ladder Diagram Arrangement Display

Performing the Simulator Based on PLC for Operating the Bridge Bodies Analogy when Opening or Closing

In this subsection contains 3 subtopics which include (i) performance when synchronizing between the physical prototyping and the PLC control system, (ii) observation for reading the sensors installed, and (iii) observation and measurement of the time of the lifting or lowering process of the bridge bodies analogy assisted by the hydraulic system.

Performance when synchronizing between prototype and PLC control

The performance of simulator for operating the bridge bodies analogy when it is opened or it is closed. The PLC control system is guided by the initials of idea and design. The bridge bodies analogy operates in two modes, i.e., manual and auto mode. Manual mode is used for operator convenience during maintenance, checking, and handling when an error step occurs. When manual mode is activated, the bridge bodies can be liftered and lowered manually without having to touch the #1 or #2 ship reader sensors on the bridge bodies. When the bridge bodies liftered or lowered is in auto mode, the PLC for operating the bridge bodies open and close program operates. The operation panel of the simulator based on Mitsubishi PLC for operating the bridge bodies analogy when opened or closed is shown in Figure 12.

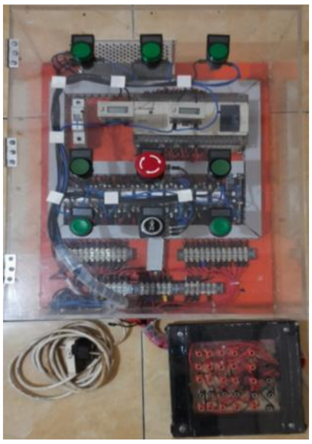

Figure 12. The Operation Panel of the Simulator Based on Mitsubishi PLC for Operating the Bridge Bodies Analogy When Opened or Closed

As shown in Figure 12, the operation panel includes (i) a push button emergency stop that functions as a system breaker and safety when checking and repairs are carried out to prevent accidents and damage to parts on the control system of opening and closing the bridges bodies analogy, (ii) a two-position selector switch that functions for manual or auto mode switching, and (iii) four green push buttons as manual buttons for UP and DOWN bridge bodies. Input from the operation panel and input from the sensor are processed in the PLC program system so that the appropriate and precise control output was produced.

Observation for reading the sensors installed

Observation of the sensor readings on the operation of the simulator for operating the the bridge bodies when the system is opened or closed can be observed from the workings of the simulator, namely, (a) the ignition step of the tool (i) make sure the 220 V-ac is on stand-by, (ii) the Miniature Circuit Breaker is in the ON position, and (iii) make sure the PLC is in the run position; (b) for the operation of the tool in auto (“A”) mode, it is done by moving the selector switch position to the auto position, for the workings of the auto mode tool, the first step is the selector position is in the auto position, the green light is ON. The ON condition, the crossbar goes up, when a ship is detected on photo sensor #1 on bridge body #1 and/or #2, the yellow light is ON for 5 seconds, the red light is ON, the warning siren is ON, the crossbar is down but if it's under the crossbar it's still there object or vehicle, the proximity sensor will read and the crossbar will not go down, the bridge bodies will open to its maximum limit and the limit switch up was depressed.

If the bridge has cleared the area and the photo sensor above bridge #1 and bridge #2 has not detected any vehicles on the bridge, after the ship has been detected by photo sensor #2 on bridge #1 and/or bridge #2, the bridge bodies will be closed to the maximum extent and the limit switch down is pressed, five seconds yellow light ON, green light ON, and warning siren OFF, for ship detection with auto conditions can be more than one ship. The principle of operation is in manual mode, simply by moving the selector

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switch to the manual ("M") position, closing the doorstop and turning the red traffic light "ON". For the opening of bridge 1, the push button of the bridge selection 1 UP is pressed on the control panel, while for the closure of the miniature bridge body 1, the push button of the bridge body #1 "DOWN" is pressed on the control panel. For the opening of bridge 2, the push button for bridge selection 2 is "UP" on the control panel, while for closing the miniature bridge body 2, the push button for bridge body #2 "DOWN" is pressed on the control panel. In an emergency condition, pressing the emergency stop button, then the system is in "OFF" condition. Based on the operating principle of the simulator, it is observed for the sensors installed on the simulator, whether they are functioning as programmed into the PLC.

The observation and measurement of the time of the lifting or lowering process of the bridge bodies analogy assisted by the hydraulic system

The measurement of the lifting or lowering process of the bridge bodies analogy assisted by a hydraulic system is one of the benchmarks for whether the prototype operates normally and as desired. The observation and measurement of the lifting or lowering process of the bridge body analogy #1 (Table 2).

Table 2. The Observation and Measurement of the Lifting or Lowering the Bridge Body #1

Observation to	**System Operation**	**Choice of Operation Mode (seconds)**	
		auto	**manual**
1	Liftering	3.08	3.06
	Lowering	2.16	2.18
2	Liftering	3.11	3.05
	Lowering	2.17	2.20
3	Liftering	3.05	3.09
	Lowering	2.11	2.15
4	Liftering	3.15	3.09
	Lowering	2.22	2.14
5	Liftering	3.10	3.04
	Lowering	2.19	2.11

The observation and measurement of the lifting or lowering process of the bridge body analogy #2 (Table 3). Based on the results of observations and measurements, it can be seen that when the auto mode of lifting the bridge body, both on bridges body #1 and #2, is longer than the process of lowering the bridge bodies. It is more emphasized on the existence of gravitational force. The process of lifting and lowering the bridge body #1 is slightly longer than the lifting and lowering of the bridge body #2. The time difference is due to a slight difference in the performance of the bridge body hydraulic pump motor, however, the difference in time with a difference that is not too large is considered tolerance. For conditions with manual mode selection in the lifting and lowering process for operating the two of bridge body, there is no significant time difference compared to the auto mode selection.

Table 3. The Observation and Measurement of the Lifting or Lowering the Bridge Body #2

Observation to	**System Operation**	**Choice of Operation Mode (seconds)**	
		auto	**manual**
1	Liftering	2.75	2.68
	Lowering	1.96	1.88
2	Liftering	2.88	2.78
	Lowering	2.04	1.92
3	Liftering	2.83	2.86
	Lowering	1.91	1.94
4	Liftering	2.72	2.91
	Lowering	1.86	1.82
5	Liftering	2.92	2.78
	Lowering	2.06	1.84

CONCLUSION

The research objectives have been supported by a number of stages in the research methods and the acquisition of results. The physical form of a PLC-based simulator for operating the analogous of bridge bodies when opened or closed was carried out by manufacturing the physical of the bridge bodies, hydraulic systems, and crossbar mechanism. The circuit and components of each system for the realization of a miniature bridge bodies as a prototype system based on Mitsubishi PLC were necessary to be assembled and integrated. Addressing the input and output on the PLC must be determined to facilitate the programming and wiring process. Finally, the stages for performing the simulator assisted by PLC and driven by GX Work of Mitsubishi could be realized according to the initials of idea and design for selecting and determining the hardware and software.

REFERENCES

[1] Tirta, S., and Goeritno, A., "Simulator Berbasis PLC untuk Pengaturan Lalu-lintas Jalan Raya pada Perlintasan Jalur Kapal," *Jurnal RESTI*, vol. 4, no. 6, pp.1007-1016, 2020, https://doi.org/10.29207/resti.v4i6.2668

[2] Ahmed, Y.E.E. Agoub, A.M.A., and Idris, F.E.A., "Design and Simulation of an Embedded Computer System for Fabric Structure," *International Journal of Computer Application*, vol. 64, no. 7, pp. 24-27, 2013, http://dx.doi.org/10.5120/10647-5405

[3] Liu, X. Chen, X., and Kong, F., "Utilization Control and Optimization of Real-Time Embedded Systems," *Foundations and Trends® in Electronic Design Automation*, vol. 9, no. 3, pp. 211–307, 2015, https://doi.org/10.1561/1000000042

[4] Jiang, K., *Security-driven Design of Real-time Embedded Systems*, Ph.D. Dissertation, Department of Computer and Information Science, Linkoping University, Linkoping, Sweden, 2016, http://www.diva-portal.org/smash/get/diva2:881552/FULLTEXT01.pdf

[5] Bhunia, S., and Tehranipoor, M., "A Quick Overview of Electronic Hardware," *Hardware Security*, pp. 23–45, 2019, https://doi.org/10.1016/b978-0-12-812477-2.00007-1

[6] Kandray. D.E., "Introduction to Programmable Logic Controllers," in *Programmable Automation Technologies: An Introduction to CNC, Robotics, and PLCs*. New York, NY: Industrial Press, Inc., 2010.pp. 1-29.

[7] NEMA (the National Electrical Manufacturers Association). 2013. NEMA ICS 61131-1-2005 (R2013). [Online] Available: https://www.nema.org/Standards/ComplimentaryDocuments/ICS%2061131%201-2005(R2013)-contents-and-scope.pdf

[8] Bolton, W., *Programmable Logic Controllers*, 6th ed. Burlington, MA: Newnes, 2015, pp. 1-19.

[9] Patel, D., *Introduction Practical PLC (Programmable Logic Controller) Programming*. Munich, Grin Verlag, 2017.

[10] Goeritno, A., and Pratama, S., "Rancang-Bangun Prototipe Sistem Kontrol Berbasis Programmable Logic Controller untuk Pengoperasian Miniatur Penyortiran Material," *J. Rekayasa Elektrika*, vol. 16, no. 3, pp.198-206, Desember 2020, http://dx.doi.org/10.17529/jre.v16i3.14905

[11] Hang Xu and Jiule Tian, "Design of auto disturbance rejection control system for pneumatic manipulator based on PLC Technology," *2020 3rd International Conference on Mechatronics and Computer Technology*, ttps://dx.doi.org/10.1088/1742-6596/1678/1/012065

[12] Ahmed, Md.L., Kundu, S., and Rafiquzzaman, Md., "Automatic Bottle Filling System Using PLC Based Controller," *MAT Journals*, vol. 4, no. 1, pp. 17-24, 2019.

[13] Olorunda, P.A., and Adetunde, I.A., "Design of PLC Based Automatic Flat Bottle Label Adjuster," *IOSR Journal of Research & Method in Education (IOSR-JRME)*, vol 8, issue 4, pp. 1-5, (Jul.-Aug.) 2018, https://dx.doi.org/10.9790/7388-0804010105

[14] Pawar, R., and Bhasme, N.R., "Application of PLC's for Automation of Processes in Industries," *Int. Journal of Engineering Research and Applications* (*IJERA*), vol. 6,

no. 6, pp. 53-59, june 2016, https://www.jera.com/papers/Vol6_issue6/Part%20-%203/I0606035359.pdf.

[15] Alphonsus, E.R., and Abdullah, M.O., “A review on the applications of programmable logic controllers (PLCs),” *Renewable and Sustainable Energy Reviews*, vol. 60 (C), pp. 1185-1205, July 2016, https://doi.org/10.1016/j.rser.2016.01.025

[16] Saleh, M.S., Mohammed, K.G., Shuker, Z.S., and Sameen, A.Z., “Design and Implementation of PLC-Based Monitoring and Sequence Controller System,” *Journal of Advanced Research in Dynamical and Control Systems*, vol. 10, no. 02, pp. 2281-2289, January 2018.

[17] Langmann, R. and Stiller, M., “The PLC as a Smart Service in Industry 4.0 Production Systems,” *Applied Science*., vol. 9, no. 3815, pp. 1-22, Sept. 2019, https://www.mdpi.com/2076-3417/9/18/3815/htm.

[18] Choudhary, A. and Abidi. S.B. “PLC based Sorting System using Metal Detection,” *International Research Journal of Engineering and Technology* (*IRJET*), vol. 07, no. 04, pp. 6350-6355, Apr. 2020,

[19] Ebert, C., and Salecker, J., “Embedded Software– Technologies and Trends,” *IEEE Software*, vol. 26, no. 3, pp. 14-18, 2009, https://doi.org/10.1109/MS.2009.70

[20] Rodriguez-Sanchez, M.C., Torrado-Carvajal, A., Vaquero, J., Borromeo, S., Member, and Hernandez-Tamames, J.A., “An Embedded Systems Course for Engineering Students Using Open-Source Platforms in Wireless Scenarios,” *IEEE Transactions on Education*, vol. 59, no. 4, pp. 248-254, Nov. 2016, https://doi.org /10.1109/TE.2016.2526676

[21] Garousi, V., Felderer, M., Karapıçak, C.M., and Yılmaz, U., “Testing embedded software: A survey of the literature,” *Information and Software Technology*, vol 104, pp. 14-45, July 18, 2018, doi:10.1016/j.infsof.2018.06.016

[22] Hadi, T.R., “Perancangan dan Uji Kualitas Software Simulasi Virtual “Digichip” Platform Android Penunjang Mobile-Virtual Learning Untuk Kejuruan Teknik Mekatronika”, Tesis, Program Studi Pendidikan Teknologi dan Kejuruan, Program Pascasarjana, Universitas Negeri Yogyakarta, 2018, https://eprints.uny.ac.id/64874/1/tesis-titih%20rejyasmito%20hadi-147 02251086.pdf

[23] Mitsubishi Electric Corporation. (Apr. 2015). *Programmable Controllers MELSEC-F: Programming Manual II*, Model: FX-P2-E. [Online]. Available: http://dl.mitsubishielectric.com/dl/fa/document/manual/plc_fx/jy992d88101/jy992d88101e.pdf

[24] Mitsubishi Electric Corporation. (Apr. 2015). *Programmable Controllers MELSEC-F: Hardware Manual*, Model: FX1N-HW-E. [Online]. Available: https://dl.mitsubishielectric.com/dl/fa/document/manual/plc_fx/jy992d89301/jy992d89301r.pdf

[25] Doht, S., Akagi, T., Ando, A., Zhao, F., and Liu, C., “Development of Flexible Spherical Actuator Controlled by Low-Cost Servo Valve and Embedded Controller,” *Procedia Engineering*, vol. 41, pp. 127–133, 2012, https://doi.org/10.1016/j.proeng.2012.07.152

[26] Carlsson, H., Svensson, B., Danielsson, F., and Lennartson, B., "Methods for Reliable Simulation-Based PLC Code Verification," in *IEEE Transactions on Industrial Informatics*, vol. 8, no. 2, pp. 267-278, May 2012, https://doi.org/ 10.1109/TII.2011.2182653.

[27] Ayed, M.B., Massaoudi, A., Alshaya, S.A., and Abid, M., “System-level co-simulation for embedded systems,” *AIP Advances*, vol. 10, no. 3 (035113), pp. 1-15, March 12, 2020, https://doi.org/10.1063/1.5140466

[28] Goeritno, A. Nurmansyah, D., and Maswan, M., “Safety instrumented systems to investigate the system of instrumentation and process control on the steam purification system,” *International Journal of Safety and Security Engineering*, vol. 10, no. 5, pp. 609-616, 2020, https://dx.doi.org/10.18280/ijsse.100504

[29] Goeritno, A. Nugraha, I., Rasiman, S., and Johan, A., "Injection current into the power transformer as an internal fault phenomenon for measuring the differential relay performance, " *Instrumentation Mesure Métrologie.*, vol. 19, no. 6, pp. 443-451, 2020. https://dx.doi.org/10.18280/i2m.190605