Article

Waterfall pattern using Omron CP1E PLC, Fuzzy Logic Method, and PLC-IoT approach

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Abstract: Programmable Logic Controller (PLC) used in data processing is OMRON Corp's CP1E type. In this research, a prototype was produced using a solenoid valve amounting to 24 which will be used as output for sequential water based on timer and presser given on parameters. Five experiments are basic patterns: chessboard triangle, zebra cross, off shift, and on shift. The experiment used fuzzy logic parameters to obtain accuracy in the waterfall; the timer is on the ladder diagram to provide the value of the combination of falling water that varies on each pattern. The accuracy value in the range 0-1 on one experiment is off-shifted. At the value of 0.206 bar presser, the water accuracy level is 0.811. At the 0.41 bar presser level, the accuracy level is 0.532; the conclusion produced by the presser is very influential on the water accuracy level at the waterfall. This research applies a PLC approach to the Internet of Things (IoT) for flexibility control and monitoring needs.

Keywords: PLC, PLC-IoT, Ladder Diagram, waterfall, Solenoid Valve.

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1. Introduction

Technological advances continue to increase over time. So is the rapid development in electronics and digital control systems. One technology that is quite famous in electronics and control systems is PLC [1, 2, 3, 4, 5]. The extension of the PLC is a programmable logic controller. From the name, PLC can be defined as electronic equipment that the system works in the digital form that can control and can be programmed as needed. PLC has a microprocessor that will store and run the program so that the speed of PLC in executing the program is very high. The speed is in milliseconds. A PLC has input and output modules, CPU, and software to write programs in digital logic. One of the most well-documented programs in PLC is the ladder diagram (LD). With this software, it will be easier to monitor and find troubleshoot with the help of a simulator program. Based on the description with the sophistication and speed in processing the digital data, then made "Dynamic Waterfall using Fuzzy logic on PLC Omron CP1E," which uses a solenoid valve as output equipment, open and close in accordance with the timer settings of the program that has been made. The solenoid will control the discharge of water to form a pattern of zig-zag and some letters in the alphabet. This research is expected to add insight into understanding control based on digital logic, especially on Omron PLC.

Furthermore, PLC type OMRON CP1E and other types of PLC [6, 7, 8, 9, 10, 11] are connected to devices compatible with the Internet of Things (IoT) to be controlled remotely with flexibility.

2. Literature Review

PLC used in this research is type Omron type CP1E E60SDR-A with 60 input and output. This selection is based on the need to control the output of 24 solenoid valves and in the PLC, also equipped with a USB port that is helpful in the transfer, monitoring, and simulation of a program with a computer. In Omron CP1E E60SDR-A PLC, there are 36 Input terminals and 24 output terminals. The input terminal serves to receive signals from electronic devices to be processed by the CPU according to the program created by the user and will eventually produce an output. In this study, the output of the PLC is directly connected to the solenoid valve to control the water flow. In addition to input and output modules, this PLC comes with a USB port with a RS 232 communication system and an I / O expansion that allows for the addition of input and output. The type of data sent is binary data (bit per bit transfer), with the commonly used baud rate being 9600 (bits per second). Furthermore, In a PLC, there is a memory map. The classification of the memory map is as follows:

1. IR (Internal Relay) is used as Input controller and PLC output.
2. AR (Auxiliary Relay) is used for certain purposes, e.g., transmission counters, flags, and control bits.
3. SR (Special Relay) functions as the flag bits and control bits used to view PC operation.
4. DM (Data Memory) stores data in the form of a word (16 bit) and maintains the data when there is a power failure.
5. TR (Temporary Relay) is a memory that provides eight bits used only for logic load and out.
6. TC (Timer / Counter) is used as a timer and enumerator.
7. HR (Holding Relay) is used to store/manipulate variations of data and can be accessed word (16 bit) orbit (1 bit) and still maintains status in case of interference on PLC.
8. UM (Using Memory) on PLC type C200HS is interpreted as the memory that can be converted and transferred to ROM and will be stored on a battery that exists on the CPU.
9. LR (Link Relay) distributes data between PC by using RS 232.

In PLC, with its programming concept, the ladder diagram then used instruction in every operation control. The instruction is a digital logic on the horizontal line of the ladder diagram. The instructions are Load (LD) Load Not, OR dan OR Not (NOR), AND dan AND Not (NAND). The timer instruction on the PLC is essentially the same as the conventional timer that changes the condition of instruction after a while (depending on the length of the time setting). The timer can be divided into two kinds On delay and Off delay. Timer On delay is used to activate the instruction after a while. In contrast, the timer off delay is used to disable the instruction after a while. There are several functions related to the counter: CTU (Up counter) is the counter value that will be increased for each incoming pulse, and the contactor will change its condition if the incoming pulse has equal to set a value on the counter. CTD (Down counter) is the opposite of the Up counter. The counter value will be lowered. The contactor will change condition if the incoming pulse has equal to the setting value on the counter. CTUD (Up / Down counter) is a combination of CTU and CTD and reset. In previous studies, researchers have conducted special research on the IoT side, which is useful in the PLC-IoT theoretical approach [12,13,14,15,16,17,18,19].

Fuzzy logic was first introduced by Lotfi A. Zadeh in 1956 for the first time through his writing about the theory of the fuzzy set. Fuzzy logic is an appropriate method for solving a logic representing a value between 0 and 1. Moreover, Three fuzzy logic stages include:

1. Fuzzification is a process of altering inputs and inputs of its firm form (crisp) into fuzzy shapes and is usually issued in fuzzy sets.
2. Interference system (evaluation rule) is a reference in explaining the relation of input or input and output variables where the variables are processed and produced in fuzzy form. As the explanation between input and output is usually "IF-THEN".
3. Defuzzification is the process by which the fuzzy variable is converted to certainty (crisp) to be sent to the control devices.

Fuzzy operators consist of the same operations as the set of crisp, ranging from the union (OR relationship), intersection (AND relationship), complement, cartesian multiplication, and set differences. Implications are a way of expressing rules. Suppose given the composition of rule A and rule B. then Implications stated in: IF A THEN B, A is called an antecedent. B is called the consequent. This implication is used to determine the linguistic value and the quantitative value of B if given A. It can be used in various techniques, but the main method is used (same as AND).

In determining the status of the water pump ignition, the fuzzy logic application is used to change the input in the form of the amount of water pressure within the piping system. And to get the output of the variation of water pump ignition time and then adjusted to the range of membership on the output variable so that the status of the water pump ignition varies according to the input conditions of fuzzy logic. Moreover, In determining the ignition time, the water pump used the Mamdani method, often also known as a Min-Max method. In this method, on any rule in the form of implication ("cause and effect"), conjunctional conjunction (AND) has a minimum membership value (min), whereas the consequent combination is max (max).

Furthermore, The working principle of IoT is simple, basically IoT is a plug and play module that can be installed on a machine or line Figure 1 and Figure 2, the module is combined with an Omron PLC which has certain specifications so that it can function as a receiver, processor, and sender of data until the data can be accessed using internet connection in real time because it has a plug and play concept, then installing IoT on machines or production lines will not change the machine's default system much and will not take too much time.

The advantages PLC-IoT:

1. Monitoring Machine on the line Flexibility: by use PLC-IoT, the status of machines on the line, whether they are running, stopped, or under maintenance
2. Data Flexibility: by use PLC-IoT, getting the data related to daily production (daily production report) very easy, such as production planning, actual production, and NG
3. Paper Saving: by use PLC-IoT, can save paper usage, because the data will be stored digitally but you can still print out for your needs
4. System Monitoring Flexibility: With this IoT system, of course it can make your work, especially related to system monitoring, easier and more efficient to do so you don't have to spend a lot of time doing it.

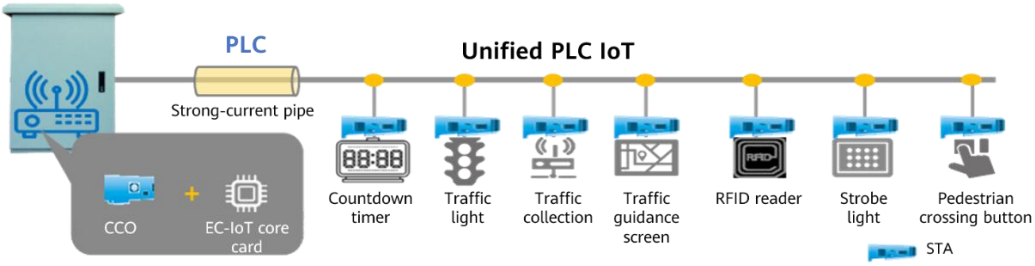

Figure 1. PLC-IoT on various application objects

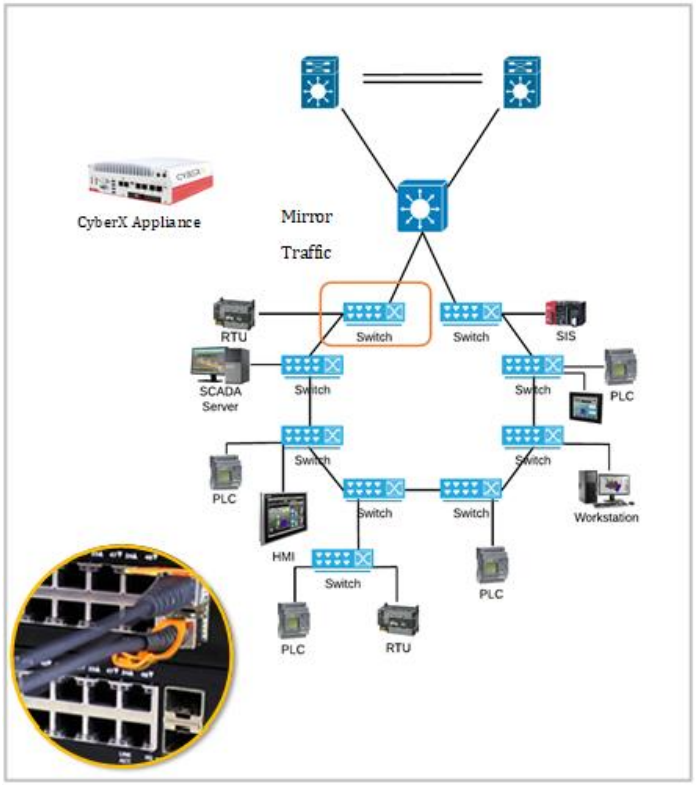

Figure 2. PLC-IoT on various Server Component

3. Methods

This chapter describes a method used to solve problems in research. The method used in this research is an experimental method by applying fuzzy logic to the control system using Omron PLC with CP1E type. In this study, there are variables to be tested and used. The variable is the parameter specified as the comparison indicator. 2 parameters determine the success of this research: timer accuracy and pressure water regulation in a piping system. Pressure is defined as the force per unit area [11]. In accordance with the physics formula to get the pressure, two conditions must be met: the force and the cross-sectional area. In this study, the force generated from electrical energy is converted by an electric motor (pump). As the pump rotates then the impeller will spin so as to push the water to move along the pipe. Pumps convert electrical energy into motion energy through a water medium along a pipe. While the cross-section area used a PVC pipe diameter 3/4 inches along the 10 meters. In this study, the maximum pressure of the pump is 6 bar. While the solenoid needs 2 bars, it needs to make a system for water pressure to be 2 bars. To answer the problem, we add overflow on the pipe system so that 2 bar pressure can get. A timer is a tool that serves to delay time. A timer on PLC has better accuracy than a conventional timer. The timer which is often used in PLC is On delay type. A timer has one activation input as well as two parameters: Timer Number and Set Value. For Timer Number filled with the timer number and Set Value are filled with a delay time value between 0000 to 9999 (999.9 seconds).

Before creating the program, it is necessary to design the input and output addresses first. This study uses PLC Omron CP1E E60SDRA with 60 input and output. This PLC provided three channels for input and three-channel for output. The input used is 0.0, 0.1, 0.2, 0.3, 0.4, 0.5 in channel 0. While the output used is 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 on Channel 100, 101, 102. Programs are made written in a ladder diagram using CX-Programmer software. The advantage of this CX-Programmer is that we can simulate the program before it is transferred to the PLC, so it allows us to modify the program if we want to change. There is also an online auto facility to monitor the program's nets. The initialization planning of input and output PLC [20, 21, 22, 23, 24] can be seen in Table 1 and Table 2.

Table 1. Input Planning of Omron PLC

Input	Function
0.0	Tombol Emegency Stop
0.1	Manual Button program 1
0.2	Manual Button program 2
0.3	Manual Button program 3
0.4	Manual Button program 4
0.5	Auto Button (program 1-4)

Table 2. Omron PLC Output Planning

Output	Function
100.0	Solenoid number 1

Output	Function
100.1	Solenoid number 2
100.2	Solenoid number 3
100.3	Solenoid number 4
100.4	Solenoid number 5
100.5	Solenoid number 6
100.6	Solenoid number 7
100.7	Solenoid number 8
101.0	Solenoid number 9
101.1	Solenoid number 10
101.2	Solenoid number 11
101.3	Solenoid number 12
101.4	Solenoid number 13
101.5	Solenoid number 14
101.6	Solenoid number 15
102.7	Solenoid number 16
102.0	Solenoid number 17
102.1	Solenoid number 18
102.2	Solenoid number 19
102.3	Solenoid number 20
102.4	Solenoid number 21
102.5	Solenoid number 22
102.6	Solenoid number 23
103.7	Solenoid number 24

This research uses 1 selector switch, 4 pushbuttons, and 1 emergency stop button. Selector switch for operation with manual mode or auto mode. For manual mode consists of 4 sub-modes, namely program 1, program 2, program 3, and program 4. As for the fourth auto mode, the program will run alternately. The emergency button is used when the entire system will stop in case of emergency when pressed. The plans of pushbutton arrangement and emergency button are shown in Figure 3.

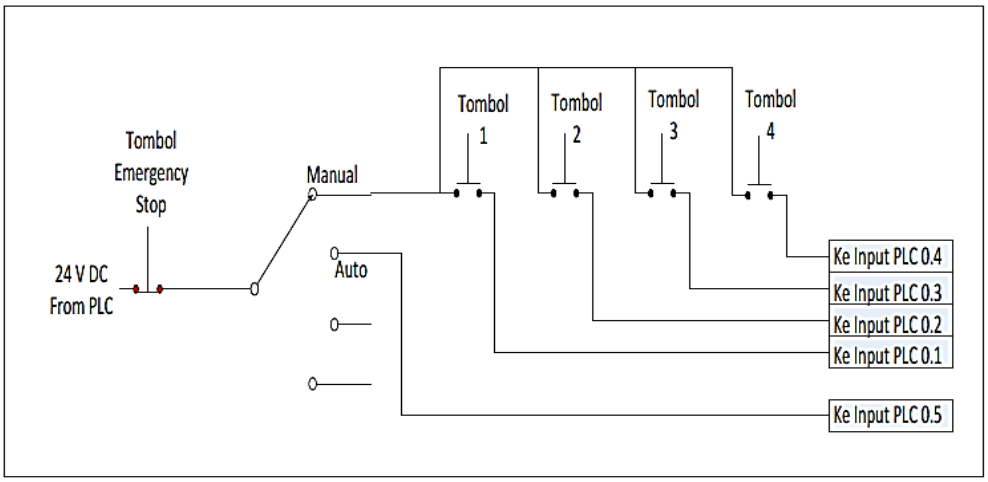

Figure 3. Push Button Design Scheme and Emergency Stop

The whole model can be grouped into two main categories, i.e., a water system can be seen in Figure 4. an electrical control system can be seen in Figure 5. 2 main parts of this research are hardware and software. Hardware includes the piping system, water tank, and frame. In contrast, the software is a program that has been created in the programming language in the form of ladder diagrams written with CX-Programmer software.

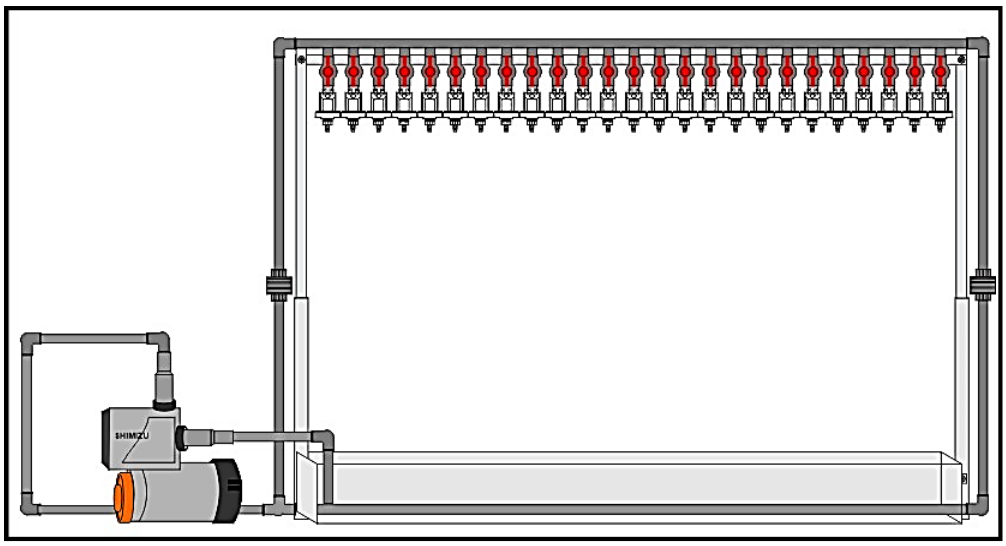

Figure 4. Overall System Circuits

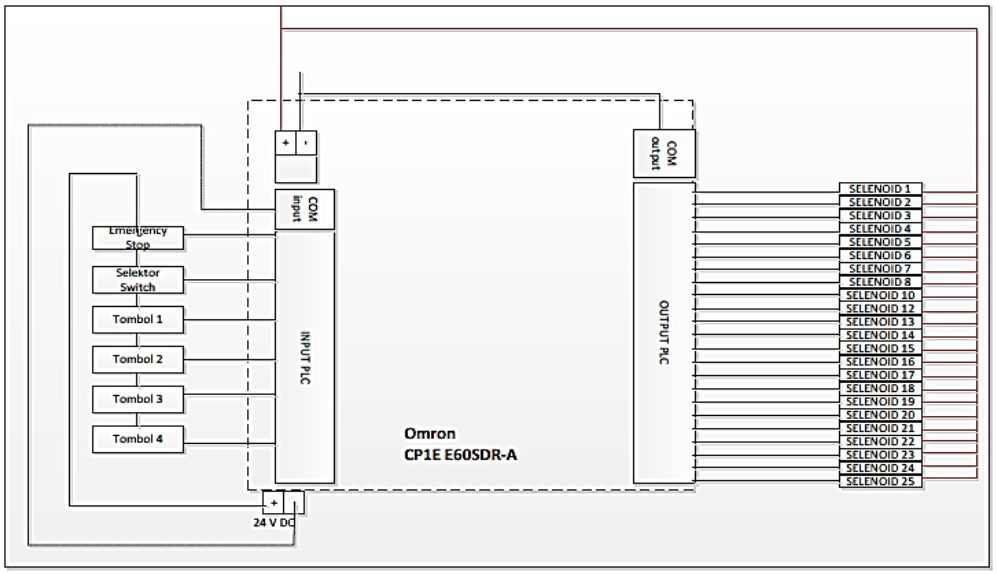

Figure 5. Overall Circuit of Omron's PLC

This research applies a fuzzy logic method to design the control system to run the water pump. The input of this fuzzy logic is the amount of water pressure in the pipe. In contrast, the output is the water pump in a spin for a long time. Figure 6. is a block of the planned fuzzy program. The control system will affect the length of time the pump is in rotation. The pump will rotate longer if the pressure inside the pipe is low. In contrast, the pump will spin for a while if the pressure water in the pipe is high. In this research, the input of the fuzzy program used three pressure sensors that have a different value of a set point. The condition of the input (pressure) is what will determine the value of the output (long rotating water pump), which varies.

In this study, the authors want to create a program that will control the solenoid valve as PLC output [25,26,27,28,29,30] so that the water output is obtained in certain patterns. There are five programs created in this research: program 1, program 2, program 3, program 4, and auto-running. To run program 1 through program four runs manually by pressing pushbuttons 1, 2, 3, 4. In comparison, the auto mode is run by directing the switch selector position to auto position. Flowchart PLC [31,32,33] System can be seen in Figure 7.

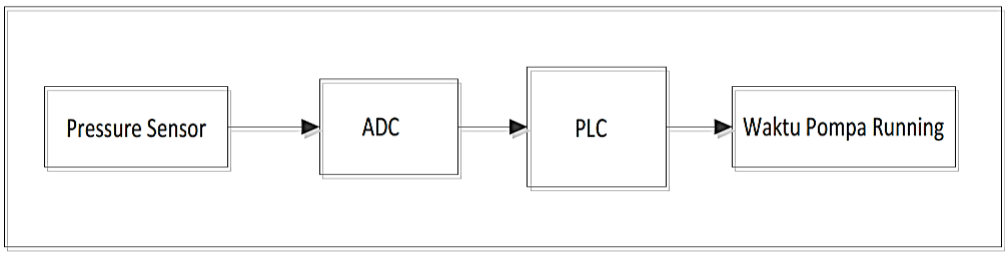

Figure 6. Block Diagram of Fuzzy Program

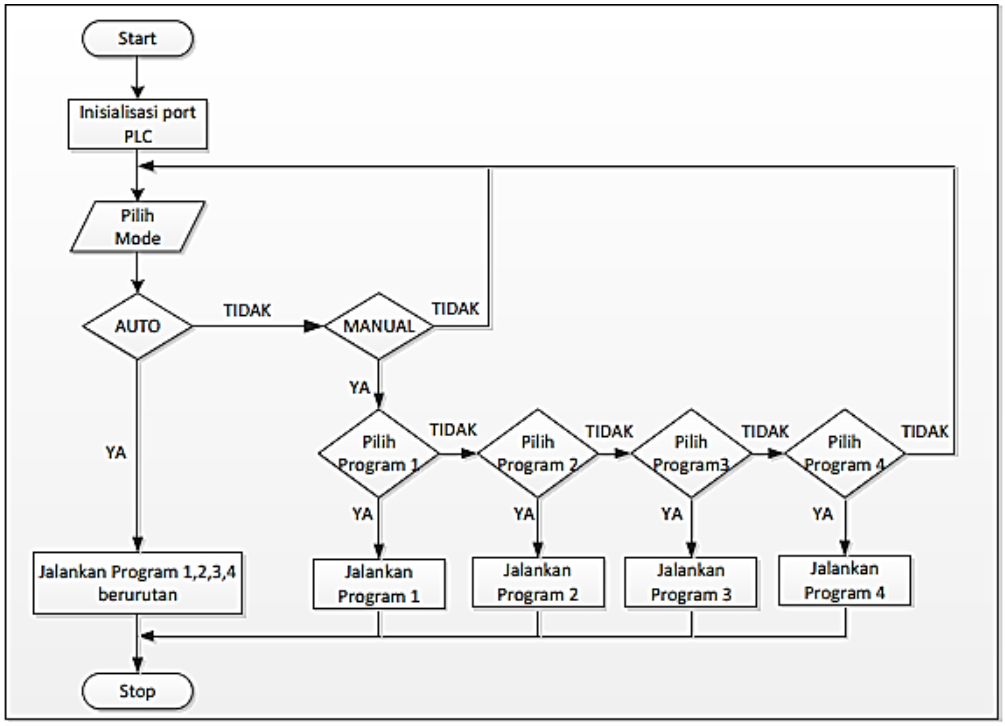

Figure 7. Flowchart PLC System

4. Result and Analyzes

In controlling the length of time, the pump spins, a membership function is created, where each value of a membership set will determine the output result of the pumping state of the pump. Starting from the first step is to determine the fuzzy set based on the input and output variables. The input variables contain pressure quantities, defined in three fuzzy sets. The triangle curve shape for the fuzzy set Medium and the shape of the right shoulder curve for the fuzzy set of High represents the variable of the pressure quantity a curve form of the right half triangle for the low fuzzy set where the horizontal axis is the input value of the pressure variable in the Bar unit, which is divided into three fuzzy set domains: Low (0-0,5) bar, Medium (0.25-0.75) bar and Height (0.5-1) bar. In contrast, the vertical axis is the membership level of the input value. The fuzzy set of pump ignition time is obtained based on the observations made prior to the water pressure within the closed-loop piping system, which is represented by the fuzzy set. In the variable ignition timing of the pump is defined three fuzzy set, which is briefly (0-0.01 sec), Normal (0.05-0.15 sec), and Long (0.01-0.02 sec). The membership function can be seen in the Figure 8 and Figure 9.

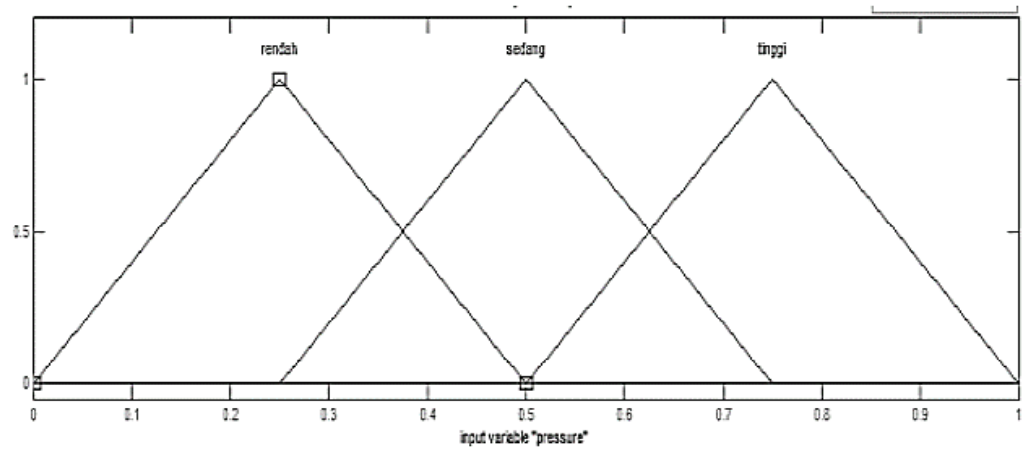

Figure 8. Membership Function In Pressure

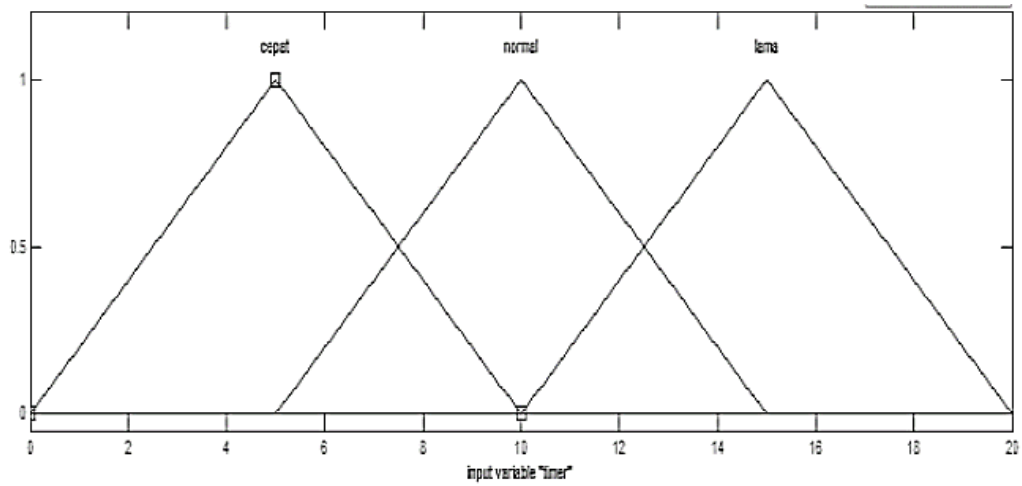

Figure 9. Membership Function Time

Here is a table-setting solenoid water valve to produce a zebra cross pattern. The test results for zebra cross Patterns can be seen in Figure 10.

Table 3. Setting the zebra cross pattern

Solenoid	**timer setting (mili second)**	**pressure (BAR)**
Sel.1-24	5	0.4

Table 4. A setting of Chessboard Pattern Patterns

Solenoid	**timer setting (mili second)**	**pressure (BAR)**
Sel.1-24	3	0.5

Table 5. Sheet Short Pattern Settings On.

Solenoid	**timer setting (mili second)**	**pressure (BAR)**
Sel.1-24	5	0.2 – 0.8

In the sliding rhythm of Off, the timer and pressure conditions used correspond to data table 1. Table 6 shows the value of timer (ms) and Pressure (BAR) on pattern 1 (Off Shear Rhythm) on the PLC. Table. 6 Timer (ms) and Pressure (BAR) data on pattern 1 (Off Shear Rhythm) on the PLC.

Table 6. Timer (ms) and Pressure (BAR) data on pattern 1 (Off Shear Rhythm) on the PLC

Solenoid	timer setting (mili second)	pressure (BAR)
Sel.1-24	10	0.2-0.4

Figure 10. Zebra Cross Patterns

Figure 11 is a Chessboard Patterns and Figure 12 is a Pattern Result 2 (Triangle), here is table setting solenoid water valve to produce Chessboard Pattern. Furthermore, Table 7 is a measurements on pattern 2 using a pressure 0.4 Bar.

Figure 11. Chessboard Patterns

Table 7. The measurement in pattern 2 uses a pressure of 0.4 Bar.

Solenoid	timer setting (mili second)	pressure (BAR)
Sel.1,2,3,5,6,7,8,9,15,16,17,24	9	0.4
Sel. 4,12,20	5	0.4
Sel.10, 13, 14,18, 19,21,22,23	7	0.4

Figure 12. Pattern Result 2 (Triangle)

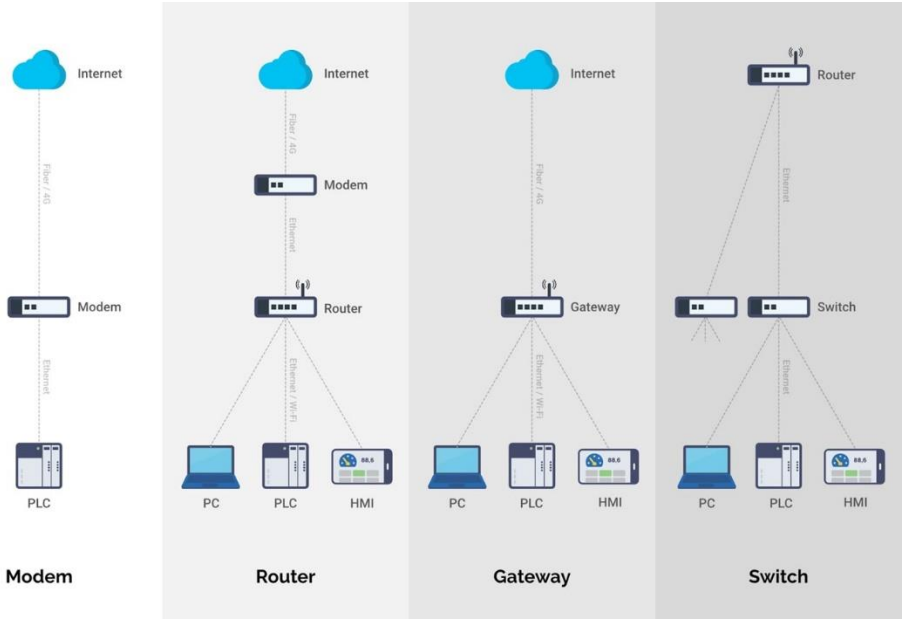

Figure 13. Modem vs Router vs Gateway vs Switch for PLC

An edge gateway, also called IoT edge gateway, serves as a network entry point for devices typically talking to cloud services. Edge gateways often provide network translation from networks and PLCs that use different industrial protocols. Some sensors generate tens of thousands of data points per second. An edge computing gateway can process data from an edge device (e.g. PLC, robot, sensors) and only send the relevant data back through the cloud, reducing bandwidth needs and server capacity. This can greatly impact response times, data usage and network transmission costs. Edge gateways themselves are considered IoT edge devices within an edge-computing infrastructure and commonly used for PLC to cloud connectivity.

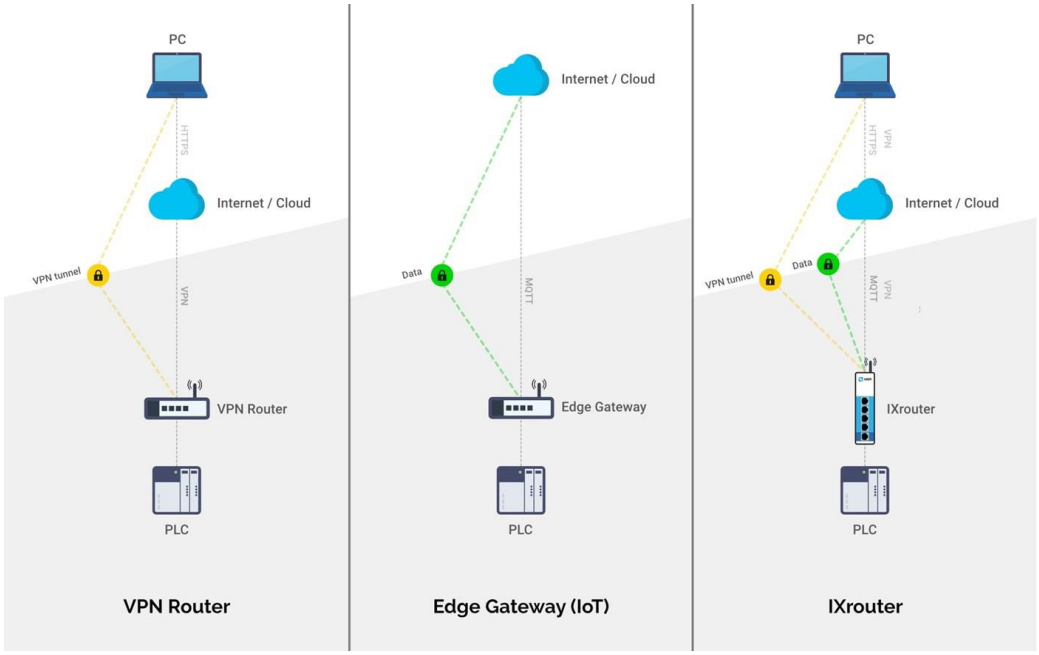

Figure 14. VPN router vs PLC IoT edge gateway vs IXrouter

Use cases when to use VPN, IoT or Edge functionality, below is a list of practical use cases when VPN and IoT functionality is needed:

- Remote troubleshooting a PLC in the field by downloading and uploading controller software over a secure VPN connection from your office. This process is called industrial remote access and reduces machine downtime and saves a lot of travel costs.
- Data logging or data acquisition from PLC's filter the data with edge technology, so only averages or maximum values within a certain interval are locally buffered and transmitted. Or you can use data triggers to send alarms when a machine breaks down.
- Transfer process data securely from PLC to the cloud for storage and deep analysis.
- Remote condition monitoring with key manufacturing metrics in historical or live dashboards.
- Perform a health check on HMI panels for your machine or cobot and control them from anywhere in the world. This helps you to improve the productivity of industrial robots. and 7 practical applications of IoT in industrial automation.

IXrouter: a combined industrial VPN router, IoT edge gateway, switch and Wi-Fi access point. The IXrouter is an industrial IoT edge gateway enriched with smart functionality for multiple purposes. It is a hardware gateway to connect industrial devices easily to the IXON Cloud platform. In the IXON Cloud, you manage all your devices, control and access them securely from anywhere, collect data insights and make these actionable in (shareable) dashboards and alarms.

The IXrouter is the bridge between machines and the IXON Cloud platform and is a VPN router, edge gateway and Wi-Fi hotspot in one single device.

- Set up a secure encrypted VPN tunnel from your PC to any PLC.
- The IXrouter supports port forwarding to access devices in the machine's network. And access to a second subnet, for example when there's a network behind the PLC or another router.
- The built-in firewall separates the machine network from the factories network to prevent hackers from accessing confidential information.
- Allow your PLC to connect over the internet and the Wi-Fi model comes with a Wi-Fi hotspot.
- Protocol translation from PLC to cloud. Support for OPC-UA, Modbus TCP, Siemens S7, Ethernet/IP and BACnet.
- It comes in an Ethernet, Wi-Fi or 4G/LTE model with 4 LAN and 1 WAN ports. Connect the IXrouter to a switch to expand the machine network.
- Support for Mobile VPN, OTA firmware updates, Stealth VPN modus and more.

5. Conclusions and Suggestion

The conclusion of dynamic waterfall design using Omron CP1E PLC is an accurate digital-based control using Omron PLC using a solenoid water valve has been successful by trying different patterns, electrically solenoid valve which is functioned as automatic water faucet already can be controlled well using PLC, The replica of the waterfall has been successfully created using a PLC with five basic patterns. And water pump works automatically based on pressure, prototype equipped with the pressure meter. The advantages PLC-IoT are a Monitoring Machine on the line Flexibility: by use PLC-IoT, the status of machines on the line, whether they are running, stopped, or under maintenance, Data Flexibility: by use PLC-IoT, getting the data related to daily production (daily production report) very easy, such as production planning, actual production, and NG, Paper Saving: by use PLC-IoT, can save paper usage, because the data will be stored digitally but you can still print out for your needs, and a System Monitoring Flexibility: With this IoT system, of course it can make your work, especially related to system monitoring, easier and more efficient. Suggestion, from this research, specific results have not been obtained on the IoT Server, from data bits per second (bps) and other data from uplink and downlink from the on and off movement of the solenoid valve in Water Pattern, and need to be shown in the next research.

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