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Design and Implementation of an HMI-Based Monitoring System for Automatic Water Purification

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Abstract

Water is one of the basic things in human life, even every living thing needs water to survive. But in reality, there are many villages in Indonesia that experience environmental problems, one of which is water pollution. Lack of clean water is a problem in this research. This research aims to find out the design and development of an automatic water purification system based on PLC and HMI, find out how to increase the efficiency of the water purification process through automation, and provide a user interface for monitoring and control of the system. This research method uses the discussion method, literature method, and observation method. Program testing on PLC and HMI-based water purification equipment is using the CX Programmer program and visualization on the CX designer. By using CX Programmer and CX Designer assisted by other PLC and HMI tools or systems, the water purification system can be controlled and monitored automatically. The water purification system can improve the efficiency of the water purification process through the development of CX Programmer and CX Designer programs such as program performance monitoring, process control, data review, analysis and inspection of the system. Integrating CX Programmer and CX Designer through the same observation of each CX Designer object with the instructions in the CX Programmer program created and can involve between CX Designer software installed on a laptop for PL.

Keywords: PLC (Programmable Logic Controller), HMI (Human Machine Interface), Water Purification

INTRODUCTION

Water is one of the most fundamental needs for human life and other living things because it plays a role in basic needs such as drinking, cooking, hygiene, and the body's biological processes [1]. However, water quality issues in Indonesia remain a serious problem with widespread impacts on public health and the environmental ecosystem. From an environmental perspective, water pollution remains a widespread problem at the village/sub-district level. Based on data from the Central Statistics Agency (BPS) in 2021, it was found that there were 10,683 villages/sub-districts in Indonesia experiencing water pollution [2]. The causes are diverse, including household waste and industrial waste, spread across various provinces such as Central Java, West Java, East Java, Kalimantan, and

Sumatra. These statistics indicate that water pollution is a significant problem that requires effective technological and system management to provide clean water to those in need.The widespread problem of water pollution has a direct impact on the availability of clean water, a basic right of every citizen. In many areas, the quality of surface and groundwater is degraded due to physical, chemical, and biological contaminants, which can cause waterborne diseases if not properly managed. Previous research has shown that rivers and strategic water sources in various regions of Indonesia are indicated as polluted based on BOD, COD, and total coliform parameters [3], [4]. To overcome these challenges, an integrated and efficient technological solution in the management and monitoring of water purification processes is needed. Automation of water treatment processes using Programmable Logic Controllers (PLCs) has proven effective in stably controlling various process parameters, such as water levels, pumps, and other sensor parameters in industrial automation systems [5]. The integration of PLCs with Human Machine Interfaces (HMIs) provides significant advantages in terms of real-time monitoring and intuitive interface control for operators, including the ability to clearly display system conditions and process parameter information visually on the HMI screen. According to relevant research, PLC systems integrated with HMI in water filtration applications have been proven to facilitate effective operation and monitoring of the filtration process [6]. In a study on the design of a PLC and HMI-based water filtration system, the use of an HMI interface allows operators to view important parameters such as water turbidity and sensor integration in real time so that the control process can run optimally.

A Human Machine Interface (HMI) is defined as a visual device that enables two-way interaction between humans and automated systems, which in industrial applications is essential for directly monitoring and controlling process flow [7]. HMIs display process information graphically so operators can observe and adjust operational parameters more easily than manual methods. This also increases the speed of reaction to abnormal conditions or process disruptions. Given the problem of clean water shortages due to water source pollution, a system is needed that not only performs automatic water treatment but also provides intuitive and responsive process monitoring for operators. This provides a strong foundation for the author to develop the design and programming of an HMI for a PLC-based automatic water purification system, in order to provide a practical and effective solution to this clean water problem.

RESEARCH METHODS

The research methodology used in this study is the design and implementation method, which includes the stages of system design, hardware and software creation, and testing the function of the PLC and HMI-based automatic water purification system.

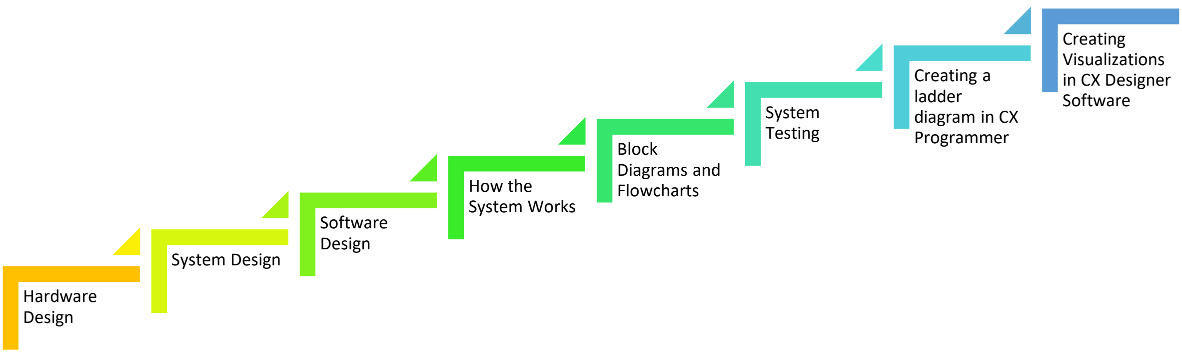

Fig 1. Automatic Flowchart

1. System Design

The initial stage of the research was carried out by designing an automatic water purification system consisting of five main containers: a dirty water container, a chemical mixing container, a sedimentation container, a water quality determination container, and a clean water container. Each container was designed to have a specific function in the water purification process. This system was controlled by an Omron CP1E-N30 PLC as the main controller and a CX Designer-based HMI as the monitoring and control medium.

2. Hardware Design

The system hardware includes a PLC, an ultrasonic sensor to detect water levels, a water pump, a mixer motor, a 220 V relay to control the load, a selector switch, push buttons, and a control panel. The ultrasonic sensor detects the water level in each container, while the pump moves water between containers according to the process sequence. All components are assembled according to a closed-loop system block diagram.

3. Software Design

The software was designed using CX Designer to build the HMI display and a PLC program to configure the system's logic. Communication between the HMI and PLC was achieved via an RS-232 cable. The program was designed with two operating modes: manual and automatic, which can be selected using a selector switch.

4. How the System Works

In automatic mode, the system works sequentially without operator intervention after being activated, starting from filling dirty water, mixing chemicals, sedimentation, filtration, to separating clean water and dirty water.

In manual mode, the operator can control each process directly using push buttons on the panel and virtual buttons on the HMI, making it easier to test and monitor the process.

5. Block Diagrams and Flowcharts

Block diagrams are used to depict the overall workflow of a system, showing the relationships between inputs, processes, and outputs within a closed system. Manual and automated flowcharts are designed to visualize the logical sequence of the system's work in each operating mode.

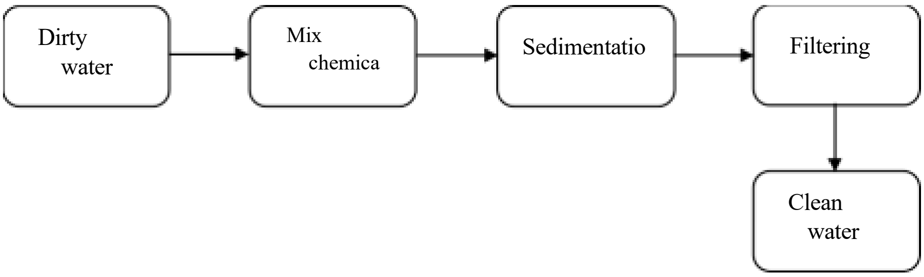

Fig 2. Block Diagram

6. System Testing

The final stage of the research involved system function testing to ensure all components, sensors, pumps, and HMI displays were operating as designed. The testing aimed to evaluate the reliability of the monitoring system, the accuracy of water level control, and the performance of the automatic water purification system.

7. Creating a ladder diagram in CX Programmer

The ladder diagram in CX Programmer is a method for programming a Programmable Logic Controller (PLC) using a graphical representation resembling a ladder diagram. This diagram consists of several elements, such as contacts, coils, timers, binaries, and muhmans, arranged in a logic circuit.

Discussion

8. Creating Visualizations in CX Designer Software

Where the design for the process that occurs in the HMI-based automatic water purification system tool as the monitoring itself, we use the application, namely CX Designer, which will create a visualization with an I/O address connected to the I/O address used on the PLC. The design is the same as the shape of the tool because the CX Designer application is used for monitoring and control [8],[9]. The design must be connected to the PLC so that the control carried out by CX Designer is connected to the PLC, then the design that has been made in CX Designer is compiled and downloaded first by means of a program that has been made by CX Programmer transferred to the PLC.

RESULTS AND DISCUSSION.

CX Programmer Testing on Automatic Water Purification System shows a control ladder diagram for an automatic water purification system. The first step in running this program is to connect a 220VAC power source and turn on the MCB, then turn the selector switch to automatic. Use the simulation feature in CX-Programmer to test the program without having to run it on actual hardware. This helps detect logic errors in the program. Direct testing is carried out by operating the water purification system. At this stage, CX-Programmer is used for online monitoring. This feature allows for real-time monitoring of the PLC input and output status while the program is running. This is very useful for verifying that all sensors and pumps are functioning as expected based on the program logic.

The initial step in testing this program is by clicking the push button on the CX Programmer with the input address 0.00 when the push button is activated it will turn on pump 1 (100.00) which will work for 1 minute. When pump 1 works then the water in container 1 will move to container 2, container 2 functions as a place to mix cloudy water with chemicals such as alum and chlorine. Binary increment will work to increase the value limited to 60 by the comperator, when it reaches 60 then IR1 will work with the address 200.00. When IR1 works, at the same time disconnect the path in pump 1 by installing Normally Close (NC) with the same address.

Fig 3. Pump 1 ON

After IR1 is ON, the mixer will work with the address (101.00) for 5 minutes with the address (T0). After the mixer has worked for 5 minutes, pump 2 will work for 1 minute with the address (100.01). The second binary increment will work by increasing the value to 60 which is limited by the comperator. The function of pump 2 is to move the water in container 2 to container 3, namely sedimentation.

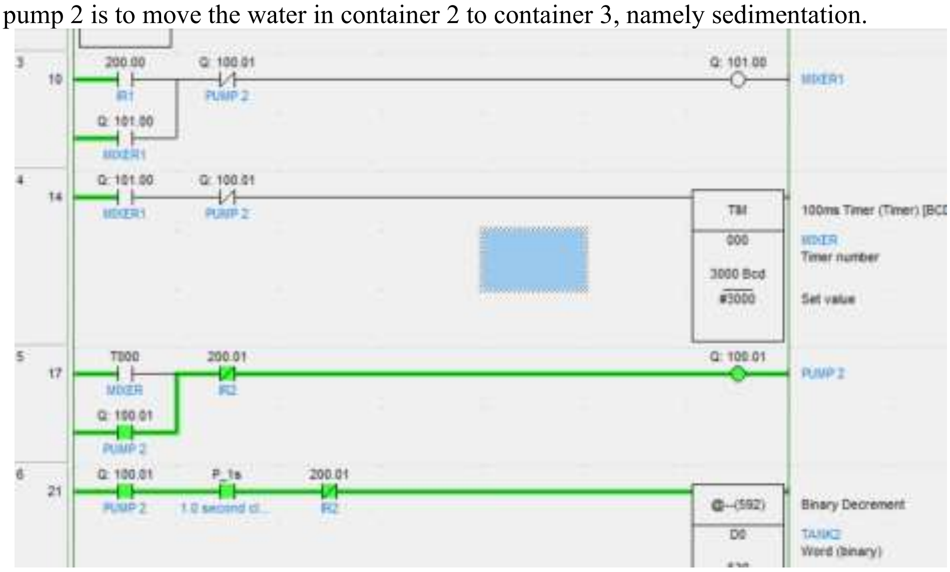

Fig 4. Pump 2 ON

When the water has reached container 3, the water is deposited for 10 minutes with the address (T01), after the water is deposited, pump 3 with the address (100.02) will work for 1 minute. The 3rd binary increment will work by increasing the value to 60 which is limited by the comperator. Pump 3 functions to carry water from container 3 to container 4, which is the determination container, before the water reaches container 4, the water enters the filtration first before entering container 4.

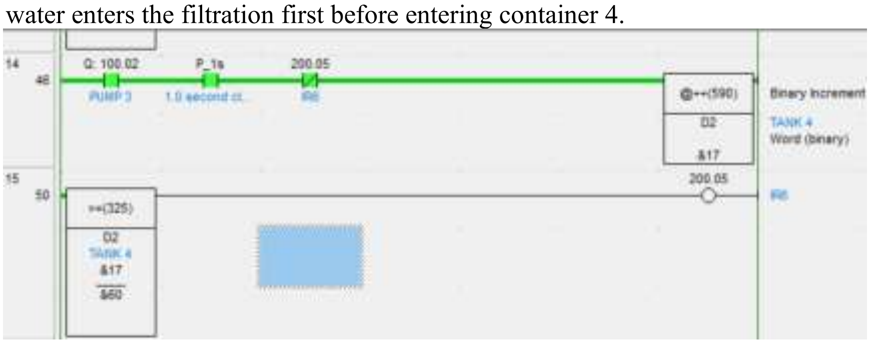

Fig 5. Pump 3 ON

After the water reaches container 4, which is the determination container, the water will be determined whether the water is still cloudy or clean if the water is still cloudy.

Then, pump 4, with address (100.04), will operate, causing the water in container 4 to return to the filter. Binary increment 4 will operate, increasing the value to 60, which is limited by the comparator. After the water enters the filter, it returns to container 4, and so on until the water is clean.

Fig 6. Pump 4 ON

If the water in container 4 is clean, pump 5, with address (100.03), will operate, and the water in container 4 will flow to container 5, the final container. The fifth binary increment will operate, increasing the value to 60, which is limited by the comparator. The water in container 5 is ready for use for toilet and toilet purposes.

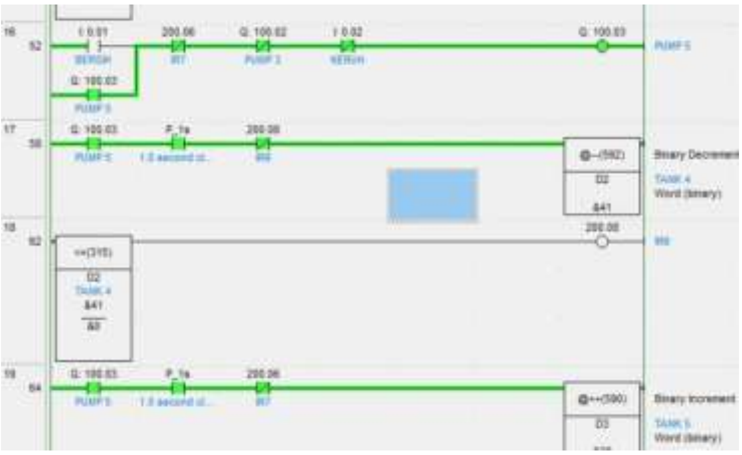

Fig 7. Pump 5 ON

Visualization Testing in CX Designer Software

An HMI can be a PC running off-the-shelf software configured for the application, with an embedded operating system and pre-packaged software. PC-based software typically offers more functionality[10]. Whether or not to choose software requires end-user configuration for the specific application. However, most applications can be handled by configuring off-the-shelf software—a simpler process. PC-based HMIs typically use the Windows operating system and provide easy connectivity to many PLC controllers. This class of HMI offers high-end performance, but is relatively expensive because the user must purchase both the PC and the HMI software.

The integration of a Programmable Logic Controller (PLC) and a Human Machine Interface (HMI) in a water purification system is accomplished by connecting the two devices so that operators can monitor and control the process automatically and easily[11], [12]. The integration process begins with selecting an appropriate communication protocol to ensure smooth data exchange between the PLC and HMI, followed by PLC programming to control all water purification system equipment, such as pumps, push buttons, indicator lights, and sensors. Furthermore, the HMI display is designed to be informative and easy for operators to understand, including process diagrams, status indicators, alarms, and manual controls. Operational data from the PLC, such as tank and pump status, is connected to the HMI display so that system conditions can be monitored in real time and actions can be taken immediately if necessary. After that, system testing is conducted to ensure the PLC and HMI work together, display data accurately, and respond quickly to commands, before the system is finally implemented and ready for use in the field.
With proper integration, operators can see what's happening throughout the water purification system and control the process using only the HMI, without having to directly interact with the hardware. Visualization testing is a crucial process in developing user interfaces for control and monitoring systems. CX-Designer is a software tool often used for designing Human-Machine Interfaces (HMI).

Visualization of an automated water purification system designed using CX-Designer. An initial simulation phase was conducted to verify that all HMI interface elements could be displayed and functioned properly before being implemented in a real system. The simulation was run in simulation mode to ensure that all indicators, control buttons, and graphics appeared as designed without any missing or obscured elements. Next, the HMI interface was connected directly to the water purification system to validate the actual data displayed, such as the water level in the tank and the operational status of the pump, so that it corresponded to actual conditions. In addition, control testing was conducted to ensure that commands given through the HMI, such as turning the pump on or off and setting process parameters, could affect the water purification system appropriately and responsively.

After performing real-time data and system control, the next step is to test the visualization in CX Designer. This visualization test is the same as the CX Programmer test, except that the testing method is different. In CX Designer, the test is performed solely through a monitor/laptop screen. By pressing the automatic push button, the visualization will run automatically on the visualization screen, and pump 1 will operate. The water in container 1 will move to container 2 through the pipes shown in Figures 8 and 9.

Fig 8. Pump Visualization1

Fig 9. Pump 1 Indicator Light ON

Fig 10. Mixer ON

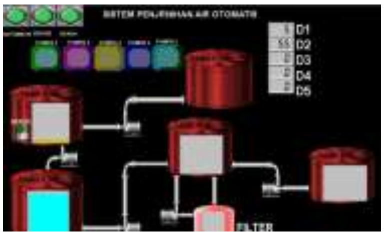

Fig 11. Visualization of Pump 2 and Container 3

Fig 12. Pump 2 Indicator Light ON

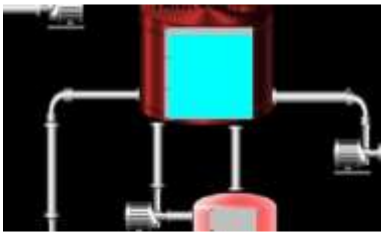

Fig13. Pump Visualization 3

Fig 14. Pump Indicator Light 3 ON

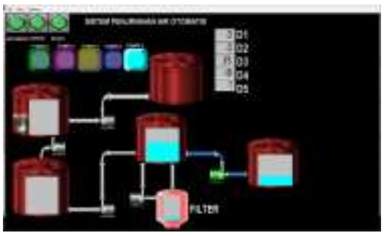

Fig 15. Visualization of Pump 5 Clean

Fig 16. Pump Indicator Light 5 Clean

In Figure 10, after the mixer has been running for 5 minutes, pump 2 will operate, and the water in container 2 will move to container 3 for sedimentation. In container 2, the water mixed with chemicals is first sedimented in container 3 for several minutes before entering container 4.

After settling, pump 3 will work to carry the water in container 3 to container 4 through the pipes in pictures 11 and 12. And in pictures 13, 14, 15, 16 it shows that tank 4 is full, so there are 2 options if the water in tank 4 is still cloudy, then press the cloudy push button which makes the water in tank 4 decrease then go to the filter tank and return to tank 4, if the water in tank 4 is clean, press the clean push button to continue to the next tank, namely the clean tank.

Ladder diagram analysis in CX Programmer

On Ladder Diagram This PLC and HMI-based automatic water purification tool uses 4 inputs and 6 outputs, in the PLC and HMI-based automatic water purification system tool circuit it has been set to work sequentially using 8 timers and 12 internal relays. Readings on pumps 1 to 5 are stored in function data memory using ladder diagram arithmetic functions which aim to make this tool work according to its function

In the CX-Designer application, the visualization of the HMI-based automatic water purification system is displayed in one main frame that functions to monitor system conditions while controlling the circuit[13],[14]. This frame displays the operational status of the main components, namely the pump, push button, and indicator lights. Each pump is visualized in the form of an icon that shows the working condition in real-time, where green indicates the pump is active and gray indicates the off or standby condition. In addition, pump control is done through the Start and Stop buttons available on the frame, so that operators can operate the system easily[15].

The indicator lights on the frame clearly display the pump's operational status, for example, a green light appears when the pump is active. The system also features a time display and timer, which helps regulate the operating duration of each purification process, including a countdown timer for the pump's operation. Integrating the CX Programmer, a ladder-diagram-based logic controller, and the CX-Designer, a visual interface, this water purification system improves process efficiency and facilitates centralized monitoring and control.

CONCLUSIONS.

The use of CX Programmer and CX Designer integrated with PLC and HMI systems allows the water purification system to be automatically controlled and monitored effectively. This integration improves the efficiency of the water purification process through system performance monitoring, process control, and real-time data analysis and evaluation to ensure alignment between planning and actual conditions. In addition, the linkage between program instructions in CX Programmer and object visualization in CX Designer allows operators to observe, control, and evaluate the system in an integrated manner through an HMI interface installed on a laptop and directly connected to the PLC.

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