Automation of water heaters in PIC-based water process trainer

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Abstract. Advances in industrial technology require workers who not only understand theory but are also able to apply technical skills directly. One of the challenges faced is how to align the learning process with industry needs, particularly in liquid heating systems commonly used across various sectors. This study offers a solution by designing the Water Process Control Trainer as a practical learning tool for automated heating systems based on PLC and HMI. The contribution of this research is to provide a learning tool that represents an industrial heating system on a laboratory scale, as well as supporting students' technical understanding and practical skills in the field of process automation. The methods used include system planning, selection, and integration of components such as heaters, PT100 sensors, Haiwell PLCs, HMIs, Solenoid valve, and water boosters. Following this, assembly and testing were conducted to ensure the heating function operates according to the designed automatic program scenario. The results of this study indicate that the system can control the water filling process, heating to a specific temperature, and automatic water return according to the predetermined setpoint. The system can also be operated via the HMI interface, allowing users to monitor and adjust parameters easily. This trainer provides a realistic learning experience that closely mirrors industrial scenarios. In conclusion, the Water Process Control Trainer is an effective practical learning tool for understanding automated heating systems and contributes to enhancing graduates' readiness to meet the demands of modern industry.

1 Introduction

The Water Process Control Trainer is a practical learning tool designed to simulate water treatment processes in industrial automation systems [1]. The device is equipped with two tanks: the first tank serves as an initial storage tank and cooler, while the second tank is used for the heating process. In this system, water is transferred from Tank 1 to Tank 2 using a water pump, which operates by creating pressure to drive the water flow. The pump is powered by an electric motor that converts electrical energy into mechanical energy through a connecting shaft between the motor and the pump's impeller [2,3]

To measure water level, a pressure level sensor is used, which operates based on the principle of hydrostatic pressure from the water column above it. The higher the water surface, the greater the pressure received by the sensor membrane, and this pressure is converted into an electrical signal that can be read by the control system [4–6]. Temperature measurement is performed using a PT100 sensor, a type of Resistance Temperature Detector (RTD) with a probe length of 20 cm. This sensor has a resistance characteristic that increases linearly with rising temperature, enabling accurate temperature readings [7–9]

The system is also equipped with two 400-watt heating elements, each designed to raise the water temperature in the tank to the set value. The heating process occurs through the conversion of electrical energy into thermal energy by the heating elements within the heater [10–12]. After the heating process is complete, the hot water is recirculated back to tank 1 using a 120-watt booster pump, creating continuous circulation.

Additionally, the system is equipped with a solenoid valve that automatically regulates water flow. The solenoid valve consists of two main parts: an electromagnetic coil (solenoid) and a valve that opens or closes depending on the condition of the electric current flowing through it [13]. The entire system is controlled by a Programmable Logic Controller (PLC), a digital electronic device capable of executing logic, timing, and calculation instructions through digital and analog input/output [14–16].

To facilitate operation and monitoring, the system is also equipped with a Human Machine Interface (HMI), which acts as an interface between the user and the machine. The HMI displays the system status in real-time and allows the operator to interactively adjust the process settings [17–19]. This Water Process Control Trainer not only illustrates the basic principles of industrial automation systems but also serves as an

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effective learning tool for comprehensive and practically integrating sensors, actuators, and PLC-based control logic [20–23].

2 Research method

This research adopts a comprehensive analysis approach to the needs of water control systems in industrial environments. The project aims to achieve two main objectives, namely accurate temperature control and the provision of practical learning media. To that end, a Water Process Control Trainer was developed, specifically designed to meet both objectives. The design process of the device includes the design of a heating tank, a stand, and an acrylic control panel to support the configuration of each component. The system consists of various devices such as water pumps, booster pumps, heating elements, and solenoid valves, integrated with water level sensors and temperature sensors. All components are integrated through the Haiwell AT12MOT PLC, equipped with the A16XDR digital extension module and the A04AI analog module, and visualized using the Haiwell C7S-W HMI. The development phase includes hardware assembly, PLC programming, and HMI interface integration.

2.1 System workflow

Fig. 1 shows the system design block diagram. The process begins when the system is activated as the starting point for the entire automation cycle. The operator first enters the set point values for the water level in Tank 1 and Tank 2 (e.g., 10 cm), as well as the target temperature on temperature sensors 1 and 2 (e.g., 28°C for cooling and 40°C for heating). The system will verify that the emergency stop button is in the OFF or standby position. If all initial conditions are met, the operator can press the Start button to initiate the automatic process. The main pump will activate and transfer water from Tank 1 to Tank 2 until the water level reaches the set point at Water Level 2. Once the water level is achieved, the pump stops, and both heaters activate to heat the water in Tank 2 until the temperature reaches the predetermined target. Once the temperature is reached, the booster pump and solenoid valve are activated to return the hot water to Tank 1. The water will refill Tank 1 until it reaches the Water Level 1 height, then the booster and valve will shut off. The hot water in Tank 1 is then cooled by the cooling system until it reaches the temperature determined by Temperature Sensor 1. After the cooling process is complete, the system has two options ; Continue automatically to the next cycle (looping), by redirecting water back to Tank 2. Or End the process by pressing the Stop button or emergency stop, and the entire system will cease operation.

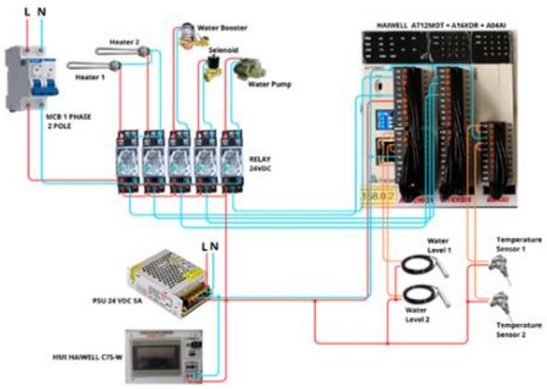


Fig. 1. System block diagram.

2.2 System wiring

Fig. 2 shows the wiring system of the water process control trainer, specifically in the heating system. The Fort LY2N 24VDC relay is used in this system to control AC voltage load devices such as pumps, boosters, solenoid valves, and heaters through the Haiwell PLC, which operates at 24V DC. In the wiring of the Trainer Water Process Control heating system, the relay coil (Coil 7) is connected to the PLC's digital output according to the specified address—for example, Y0 for the pump and Y3 for the heater. Meanwhile, the water level sensor and temperature sensor, which use a 4–20 mA output signal, are connected to the PLC's analog input channel. To support the operation of the sensors, DC voltage is supplied through the V-in terminal on the power supply. A similar principle is applied to the relay coil (Coil 8) for the AC actuator, which is powered from the V-in DC source.

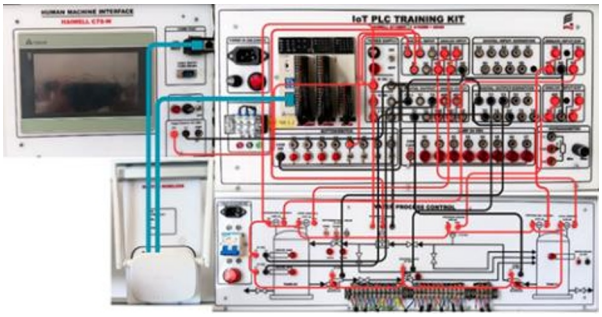


Fig. 2. Heating System wiring.

Since this system is implemented on an acrylic trainer medium, Figure 3 shows the wiring diagram of the heating system on the Water Process Control Trainer. The diagram illustrates the connections starting from digital input, analog input, digital output, to integration with HMI and router.

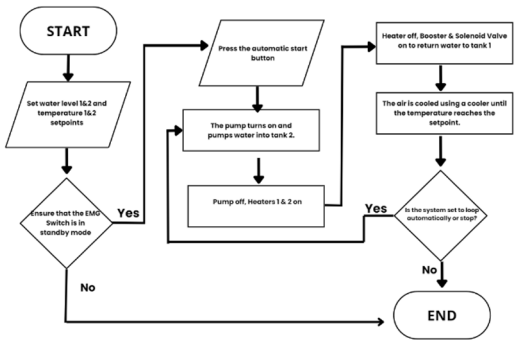


Fig. 3. Wiring the heating system on the trainer.

2.3 Ladder diagram

The ladder diagram used in the water process control trainer project is as follows in Fig. 4. Fig. 4. shows the MOV instruction in ladder diagram. The MOV (Move) instruction is a basic instruction in PLC programming that is used to copy or assign a value from a source to a destination register [1]. In the designed program, the MOV instruction is used to retrieve data from analog inputs such as the water level sensor (AI0) and temperature sensor (AI2), then copy it to the internal registers V0 and V2. These values are subsequently used as actual values that can be displayed on the HMI and serve as references for the control logic process.

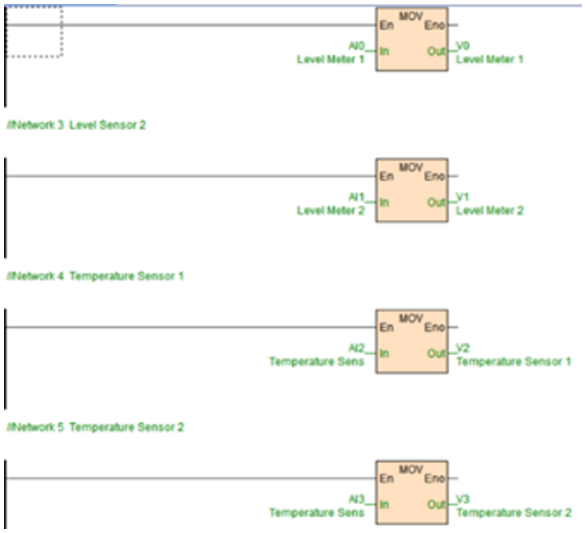


Fig. 4. Wiring the heating system on the trainer.

The manual control program allows direct for each component, such as the water pump, heater, water booster, solenoid valve, and main and emergency (EMG) internal relays. All of these components can be controlled directly through the HMI display. The automatic control program requires that the setpoint values for the water level sensor and temperature sensor be determined first before the program runs. These setpoints are set using the compare instruction. For example, for water level sensor 2 (V1 for the actual value and V51 for the setpoint), the compare instruction with the "<" (less than) operator is used to activate or trigger the water pump to turn on. This means that as long as the actual water level value is still below the setpoint (e.g., 10 cm), the pump will remain on. Conversely, to turn off the pump, a compare instruction with the operator ">=" (greater than or equal to) is used, meaning the pump will stop operating once the water level reaches or exceeds the setpoint value. After that, the program will proceed to the next process flow

3 Results and discussion

Figure 5 shows the physical appearance of the Water Process Control Trainer, this has been adapted to the design that was created beforehand. The trainer consists of several acrylic panels, including: a PLC panel equipped with digital and analog input-output terminals, a process control panel to regulate each component of the water process, an HMI panel as a mount for the Haiwell HMI, and a panel for the router. All panels are assembled in a structured manner and connected using banana jack cables to facilitate connections between components.

Fig. 5. Physical appearance of the water process control trainer.

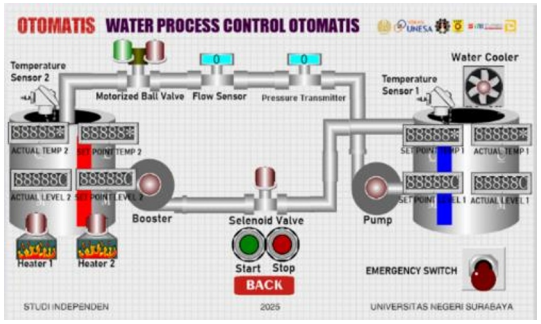
3.1 HMI display

Figure 6 (a) shows the HMI display for manual control mode, providing a user-friendly interface where each component, such as the water pump, heater, water booster, solenoid valve, and various relays, can be operated separately and independently. This setup allows operators to have full control over individual elements of the system, enabling precise adjustments or troubleshooting without affecting other parts. For instance, users can toggle the water pump on or off directly from the screen, monitor its status in real-time, and make changes as needed based on specific requirements or maintenance tasks. This mode is particularly useful in scenarios where manual intervention is necessary, such as during initial setup, testing phases, or when automated processes might need to be overridden for safety reasons. Additionally, the interface often includes visual indicators, buttons, and sliders that make it intuitive for users to interact with the system, ensuring that even less experienced operators can manage components effectively without complex programming knowledge.

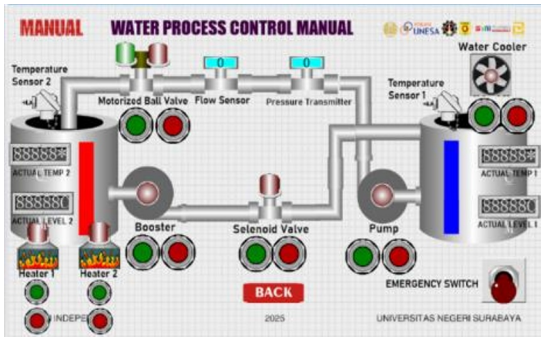
Figure 6 (b) displays the HMI interface for automatic mode, where setpoint settings for the water level sensor and temperature sensor can be directly adjusted via the HMI. Operators can easily input desired values, such as a target water level of 10 cm or a specific temperature threshold, ensuring the system responds accurately to environmental conditions. In this mode, system operation is simplified through the use of only one start and stop button, which automatically executes the entire program sequence without requiring manual control of individual components. This automation reduces the risk of human error, enhances efficiency, and allows for continuous operation once initiated, making it ideal for routine processes where consistent performance is key. Overall, the automatic mode integrates all components into a cohesive workflow, where the program logic handles transitions between stages, such as activating pumps when levels drop or adjusting heaters based on temperature readings, thereby optimizing the system's performance and minimizing operator involvement. Furthermore, the interface might feature real-time data visualization, alarms for deviations from setpoints, and logging capabilities to track system behavior over time, adding layers of reliability and ease of monitoring for industrial applications.

3.2 Testing of heater system

This study uses a quantitative approach with an experimental method to test the performance of the water heating system. The tank used has a capacity of 42 liters with a length of 40 cm, a width of 30 cm, and a height of 35 cm. In the test, the tank was filled with water to a height of 15 cm or 18 liters. To calculate the time needed to raise the water temperature, the heat energy formula was used [24, 25]. --→



(a)



(b)

Fig. 6. (a) HMI manual mode, (b) HMI automatic mode.

And since the energy is provided by an electric heater:

$$Q = m \cdot c \cdot \Delta T \tag{1}$$

$$Q = P \cdot t \tag{2}$$

then:

$$P \cdot t = m \cdot c \cdot \Delta T \rightarrow t = \frac{m \cdot c \cdot \Delta T}{p} \tag{3}$$

$$t = \frac{18.4186.1}{800} \rightarrow t = \frac{75348}{800} = 94.138\ sec \rightarrow 1\ minute\ 34\ seconds \tag{4}$$

Given:
Mass of water (m) = 18 kg
Specific heat of water (c) = 4186 J/kg°C
Temperature increase (ΔT) = 1°C
Total heater power (P) = 2 × 400 W = 800 W

So, according to calculations (4), the time needed to raise the temperature by 1 degree is approximately 1 minute and 34 seconds. The heating system was tested by recording the time and temperature in the tank, as shown in Table 1. The test was conducted from a normal water temperature of 31°C to a heated temperature of 45°C. The time required was 18 minutes and 26 seconds, with an average of 79 seconds for each increase in water temperature. Table 1 shows water heating data from 31°C to 45°C, and Figure 7 shows its graph.

Table 1. Water heating data.

Temperature	Start time	End time	Duration	Duration (Seconds)
31 → 32°C	00:00	01:04	1 minutes 4 seconds	64
32 → 33°C	01:04	02:19	1 minutes 15 seconds	75
33 → 34°C	02:19	03:37	1 minutes 18 seconds	78
34 → 35°C	03:37	04:55	1 minutes 18 seconds	78
35 → 36°C	04:55	06:11	1 minutes 16 seconds	76
36 → 37°C	06:11	07:32	1 minutes 21 seconds	81
37 → 38°C	07:32	08:48	1 minutes 16 seconds	76
38 → 39°C	08:48	10:09	1 minutes 21 seconds	81
39 → 40°C	10:09	11:29	1 minutes 20 seconds	80
40 → 41°C	11:29	12:54	1 minutes 25 seconds	85
41 → 42°C	12:54	14:15	1 minutes 21 seconds	81
42 → 43°C	14:15	15:41	1 minutes 26 seconds	86
43 → 44°C	15:41	17:03	1 minutes 22 seconds	82
44 → 45°C	17:03	18:26	1 minutes 23 seconds	83

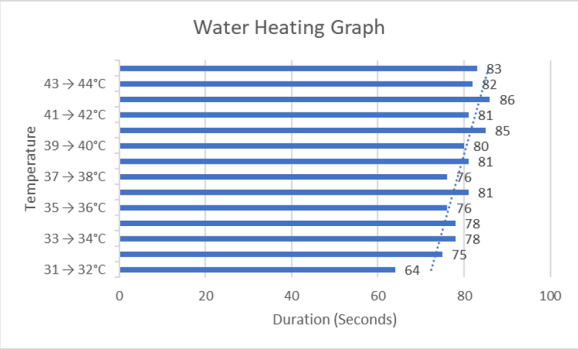


Fig. 7. Water heating graph.

4 Conclusion

This study has successfully designed and developed a PLC-based automatic water heating system, where the entire process can be monitored and controlled through an HMI interface in real time. This system is capable of performing automatic heating cycles based on setpoint values determined by water level sensors and temperature sensors in each tank. Based on the test results, the time required to increase the water temperature by 1°C averages only about 79 seconds or 1 minute 19 seconds. This figure is faster than the theoretical calculation, which estimates an average heating time of 1 minute 34 seconds for the same temperature increase. This difference is likely due to several factors, such as higher heating element efficiency than initially assumed, the influence of ambient temperature accelerating the heating process, and changes in the thermal properties of water approaching 45°C. For further development, it is recommended to integrate PID control to improve the accuracy of water filling and heating, as well as minimize system errors to ensure the process runs more stably and efficiently.

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