Distributing PID controllers applied in water-mixing process

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Abstract. In a process control system influenced by several parameters, which are usually located and separated in a large area, the one-central controller is not effective anymore. It is computationally hard for the controller hardware to do many tasks at the same time, therefore, they are considered to distribute in Local Control Units (LCUs). This research investigates the distributed PID controllers in the water-mixing process. The main controlled variables (SV) are the level and temperature influenced by three parameters (flow-in of cold water, flow-in of hot water, and flow-out of the main tank), which are then distributed to LCU-1 to LCU-3. To maintain the SV, the master controller is then designed based on the difference between SV and feedback of the main-tank (PV) so that it will deliver SV for each LCU. The results show that with control parameters in LCU-1 (Kp, Ti, Td are 2, 10, 0.46, respectively), LCU-2 (Kp, Ti, Td are 8, 6, 0.6), and LCU-3 (Kp, Ti, Td are 3, 70, 20), the response of water temperature (measured based on settling-time [Ts], % overshoot [OS], and rise-time [Tr]) are 42s, 0%, 45.3s. In the water level control, the response can be maintained with the 60s, 0%, 62s, for Ts, %OS, Tr, respectively.

1. Introduction

Nowadays, the desired process variable in industrial process control is influenced by several other physical processes [1]. The well-known process appearing in the industry is the process involving water as the main plant. Its application, such as the water-mixing process, can be found in chemicals, pharmaceuticals, building material, oil and gas, food and beverage industry [2-4]. Several researches have been addressed to find the solution in the water-mixing issues. Gao et.al investigated the influence of the inlet velocities of cold water against the characteristics of hot water inside the storage tank of the solar system. By numerical simulation, they characterized the behavior of the water mixing that will be useful for the solar system design [5]. Morosov applied Tomography techniques to investigate its application for monitoring and controlling the mixing processes [6]. The research was aimed to find an efficient processing algorithm to obtain information about the mixing process. In another research [7], Eugenia et.al proposed a thermodynamic model of the temperature in the water and steam mixing process. They showed that temperature distribution during the mixing process in the form of the exponential function. The verification experiment was conducted to approve their model.

All researches have not considered the issues of the water-mixing process in a large area. In this kind of system, the interacting processes are sometimes located in a large area and separated in long-distance, therefore the networked system such as Distributed Control System (DCS) is employed to coordinate whole parameters. The DCS can manage industrial equipment, sensors and many local control units (LCUs) to derive the global desired variable. Researches in DCS have dealt with the effectiveness of the coordinated mechanism for the various applications. Research in Xin et al. employed
DCS to coordinate several mobile robots to investigate environment circumstances such as chemical concentration, temperature, and magnetic field [8]. The DCS is also applied in the research of oil sewage treatment. In this research, it delivered high reliability and a good stability system [9]. The results of the coordinated algorithm (also known as master control) in DCS are the command signals sent to the several Local Control Units (LCUs). In this part, the PID controller is usually employed because of its simplicity and robustness [10]. From an industrial point of view, the PID controller is also reasonable because of its existing in today's industrial equipment.

This research investigates the distributed PID controllers in the water-mixing process. The main controlled variables \( SV_G \) are the level and temperature influenced by three parameters (flow-in of cold water, flow-in of hot water, and flow-out of the main tank), which are then distributed to LCU-1 to LCU-3. To maintain the \( SV_G \), the master controller is then designed based on the difference between \( SV_G \) and feedback of the main-tank (\( PV_G \)) so that it will deliver \( SV \) for each LCU.

2. Proposed control method

2.1. Master Control Unit (MCU)

Figure 1 shows the structure of water-mixing temperature control. In this part, master control sets the global error of temperature as input and then delivers three set-points for each LCU. To maintain the temperature, the MCU combines how much hot and cold water filled to the main tank based on the global error of temperature \( e_{GT} \) while keeping the level under the highest level by using LCU-3. The used rules are stated in Eq.1 to Eq.3.

\[
SV_{LCU-1} = \begin{cases} 1 (l/h), & 20 \leq e_{GT} < 2 \\ 2 (l/h), & 20 < e_{GT} \leq 55 \\ 3 (l/h), & e_{GT} > 55 \end{cases}
\] (1)

\[
SV_{LCU-2} = \begin{cases} 1 (l/h), & -2 \leq e_{GT} < 0 \\ 2 (l/h), & -25 \leq e_{GT} < -2 \\ 3 (l/h), & -55 \leq e_{GT} < -25 \\ 4 (l/h), & e_{GT} < -55 \end{cases}
\] (2)

\[
SV_{LCU-3} = \begin{cases} 1 (l/h), & 15 \leq WaterLevel < 10 \\ 2 (l/h), & 35 \leq WaterLevel < 15 \\ 3 (l/h), & 35 < WaterLevel \end{cases}
\] (3)

On the same hand, figure 2 shows the structure of water level control. The algorithm of MCU for the water level is also designed based on the global error of the water level \( e_{GL} \). In this part, only LCU-1
and LCU-3 are used with the rule as stated in Eq. 4 and 5. Those equations are subsequently applied in master control hardware from Stardom FCN-RTU Yokogawa.

**Figure 2.** The system configuration of water-mixing level control.

\[
SV_{LCU-1} = \begin{cases} 
0 & e_{GL} = 0 \\
1 & 0 < e_{GL} \leq 1 \\
2 & 1 < e_{GL} \leq 3 \\
3 & 3 < e_{GL} \leq 6 \\
4 & 6 < e_{GL} \leq 9 \\
5 & 9 < e_{GL} \leq 12 \\
6 & 12 < e_{GL} \leq 15 
\end{cases} \tag{4}
\]

\[
SV_{LCU-3} = \begin{cases} 
0 & e_{GL} = 0 \\
3 & -1 < e_{GL} \leq 0 \\
9 & -2 < e_{GL} \leq -1 \\
12 & -3 < e_{GL} \leq -2 
\end{cases} \tag{5}
\]

### 2.2. Local Control Unit (LCU)

Each LCU uses PID control where the parameters (Kp, Ki, Kd) are derived by applying Ziegler Nichols Type-2 (closed-loop). The method is to give initial parameters which are subsequently needed to enhance based on Table 1.

**Table 1.** The rule for tuning parameters.

| Parameter | Rise Time | Overshoot | Settling Time | Error Steady-state |
|-----------|-----------|-----------|---------------|--------------------|
| Kp        | Decrease  | Increase  | Minor Change  | Decrease           |
| Ki        | Decrease  | Increase  | Increase      | Eliminate          |
| Kd        | Minor Change | Decrease  | Decrease      | Minor Change       |

### 3. The setup of experiment

Master Control Unit (MCU) algorithm is written in Stardom FCN-RTU Yokogawa with Human Machine Interface (HMI) of Fast/Tools. The LCUs are applied in an 8-bit microcontroller with an Ethernet Modbus protocol. To obtain the initial control parameters, each plant, as depicted in Figure 3, is firstly set to closed-loop and then gradually increase the gain until the response reaches periodic sustained oscillation. Finally, the value of Periodic time of signal and the gain are used to calculate the initial control parameters. The hardware of the overall plant is shown in figure 4.
4. Results and discussion

4.1. Flow-in of cold water (LCU-1)

After finding the initial control parameter, the response is enhanced by referring Table 1 so the final result as shown in Figure 5 with the parameters: \( K_p = 2 \), \( t_i = 10 \), and \( T_d = 0.46 \). The response behaves with settling time 2.91s, Overshoot 1.34\%, rise time 0.71s.

4.2. Flow-in of hot water (LCU-2)

In the same way, the initial response is enhanced by tuning the parameters based on Table 1 so the final result as shown in Figure 6 with the parameters: \( K_p = 5 \), \( t_i = 10 \), and \( T_d = 0.3 \). The response characteristics are settling time 2.8 s, overshoot 1.26\%, and rise time 1.62 s.
4.3. Flow out from the main tank (LCU-3)
In this part, after finding the initial control parameter, the initial response is enhanced by referring Table 1 so the result as shown in Figure 6 with the parameters: Kp=8, Ti=6, and Td=0.6. The response behaves with settling time 2.34 s, overshoot 1.9 %, and rise time 2.2 s.

![Figure 7](image)

**Figure 7.** The response of LCU-3, a). Initial response; b). Response after tuning.

4.4. Human Machine Interface (HMI) and master control
HMI is employed for monitoring the performance of the global set-point. The realization of the HMI is depicted in Figure 8. Master Control algorithm of the Eq. 2 and 3 has the response as described in Figure 9. From the result, it shows that the proposed algorithm can successfully maintain the global temperature according to the desired global set-point. The response of water temperature (measured based on settling-time [Ts], % overshoot [OS], and rise-time [Tr]) are 42s, 0%, 45.3s.

![Figure 8](image)

**Figure 8.** HMI for the system.

On the same hand, Eq. 4 and 5 are conducted to the hardware system and show the response as depicted in Figure 10. Because the response has still error steady-state, it can be enhanced by changing the rule as stated in Eq.6 and Eq.7. The better response is shown in Figure 11 with the 60s, 0%, 62s, for Ts, %OS, Tr, respectively.

![Figure 10](image)

**Figure 10.** Global water level response.
Figure 11. Global water level response after changing the rule.

5. Conclusion
This research investigates the distributed PID controllers in the water-mixing process. The main controlled variables (SV\textsubscript{G}) are the level and temperature influenced by three parameters (flow-in of cold water, flow-in of hot water, and flow-out of the main tank), which are then distributed to LCU-1 to LCU-3. To maintain the SV\textsubscript{G}, the master controller is then designed based on the difference between SV\textsubscript{G} and feedback of the main-tank (PV\textsubscript{G}) so that it will deliver SV for each LCU. The results show that with control parameters in LCU-1 (Kp, Ti, Td are 2, 10, 0.46, respectively), LCU-2 (Kp, Ti, Td are 8, 6, 0.6), and LCU-3 (Kp, Ti, Td are 3, 70, 20), the response of water temperature (measured based on settling-time [Ts], % overshoot [OS], and rise-time [Tr]) are 42s, 0%, 45.3s. In the water level control, the response can be maintained with the 60s, 0%, 62s, for Ts, %OS, Tr, respectively. As for the simplicity of the master control rule and availability of PID controller in today's equipment, this method can be potentially applied to the industrial plant dealing with distributed parameters and wide-long distance LCU.

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