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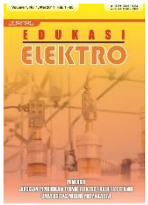

Design and Implementation of a Web Based SCADA for Closed Loop PID Control Optimized by AI with PLC Integration: A Multi-Layer Architecture Integrating Real-Time Monitoring, Intelligent PID Tuning, and Industrial Automation

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Abstract— This journal aims to design and implement a Web Based SCADA system integrated with PLC and using the Firefly algorithm for PID control parameter optimization in a closed loop system. The system is developed following the ISA-95 architecture on 1st Layer to 3rd Layer, including data collection via PLC, monitoring via SCADA, and AI-based control and analysis. The Firefly algorithm is used to automatically refine the Kp, Ki, and Kd parameters so that the control system works optimally. Testing was carried out on a liquid level control system using the LCV-01 valve control. The results showed that the Firefly method produced faster steady state time and lower overshoot compared to the manual and Ziegler-Nichols methods. The developed Web Based SCADA interface supports real time monitoring, multiuser, historical data trending, and is flexible to access via a browser without special installation. This SCADA-AI-PLC integration provides an adaptive, efficient, and economical solution for modern industrial automation.

Keywords: SCADA, Web, PID controller, artificial intelligence, PLC.

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1 Introduction

The advancement of Industry 4.0 demands adaptive and intelligent control systems that can be monitored and operated flexibly from various devices. Supervisory Control and Data Acquisition (SCADA) has become the standard solution for real-time monitoring and process control in industrial automation. However, conventional SCADA implementations are typically desktop-based and rely on licensed software, which limits accessibility and scalability. Recent developments in web technologies and cloud computing have enabled Web Based SCADA systems that provide cost-effective, flexible, and multi-user access via standard web browsers without requiring special installation [6], [10], [16], [20].

In modern SCADA architecture, the ISA-95 standard categorizes systems into multiple layers to ensure seamless integration of field devices, control systems, supervisory platforms, and enterprise management. Research has emphasized the importance of extending SCADA to Layers 1–3 for effective integration between Programmable Logic Controllers (PLCs), supervisory monitoring, and manufacturing operations [9], [7], [14]. These layers are illustrated in Figure 1.

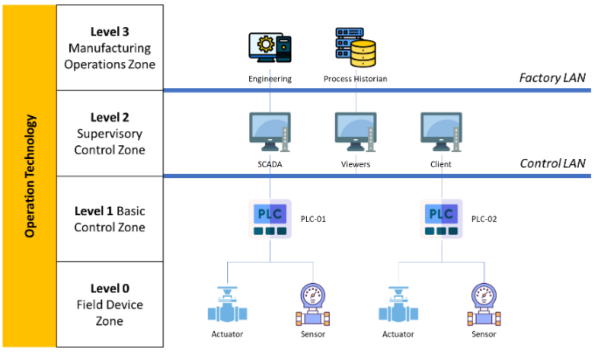

Figure 1. ISA-95 framework and layers

Layer 0 (Field Device Zone): Consists of equipment such as machines, sensors, actuators, and other devices that directly interact with industrial processes. Layer 1 (Basic Control Zone): Includes control devices such as Programmable Logic Controllers (PLCs), Remote Terminal Units (RTUs), and Distributed Control Systems (DCSs), which execute closed-loop control and other control tasks in industrial processes. Layer 2 (Supervisory Control Zone): Comprises SCADA systems and Human-Machine Interfaces (HMIs) that provide advanced supervision and control, allowing operators to monitor and control processes in real time. Layer 3 (Manufacturing Operations Zone): Responsible for production management and optimization, including planning, quality control, and resource management. Layer 4 (Site Office IT Zone): Focuses on strategic business planning, supply chain management, and integration of Enterprise Resource Planning (ERP) systems with production processes.

This research focuses on Layers 1 to 3, specifically basic control via PLCs, supervisory SCADA-HMI, and operations management, to develop an integrated, flexible, and adaptive industrial control solution.

Meanwhile, the Proportional–Integral–Derivative (PID) controller remains one of the most widely applied control strategies in industry due to its robustness and simplicity. However, traditional tuning approaches such as Ziegler–Nichols or manual trial-and-error are often inefficient and highly dependent on operator expertise. To overcome these limitations, numerous Artificial Intelligence (AI) and metaheuristic optimization algorithms have been proposed to automate PID tuning. Among them, the Firefly Algorithm has gained attention for its ability to achieve faster settling time, minimize overshoot, and handle nonlinear systems more effectively compared to classical approaches [1], [11], [13], [15], [18].

Recent studies have also emphasized the growing importance of integrating AI into SCADA and industrial control systems. For example, Rustamova and Rustamov [2] discussed the challenges of merging AI with SCADA architectures, while Zhang et al. [4] and Prakash & Verma [12] reviewed AI-enhanced SCADA platforms for data-driven decision-making. Similarly, Irawan et al. [3] and Kumar & Singh [5] analyzed AI-based PID tuning methods and metaheuristic approaches, confirming their potential to outperform conventional techniques. However, most of these studies remain simulation-based or limited to theoretical frameworks, with few addressing real-world implementation of AI-driven PID tuning integrated with PLCs and Web Based SCADA systems.

Based on this research gap, the present study aims to design and implement a Web Based SCADA platform integrated with PLCs and enhanced with the Firefly Algorithm for PID parameter optimization in a closed-loop control system. The main contribution lies in demonstrating a practical, multi-layer SCADA architecture (Layers 1–3) that is adaptive, AI-driven, and web connected, offering a flexible and intelligent solution for modern industrial automation.

2 Method

2.1 Design and Development of a Web Based SCADA

This section presents the design of a closed-loop control system optimized using AI, based on a PLC and integrated with a Web Based SCADA platform. The overall system diagram is shown in Figure 2.

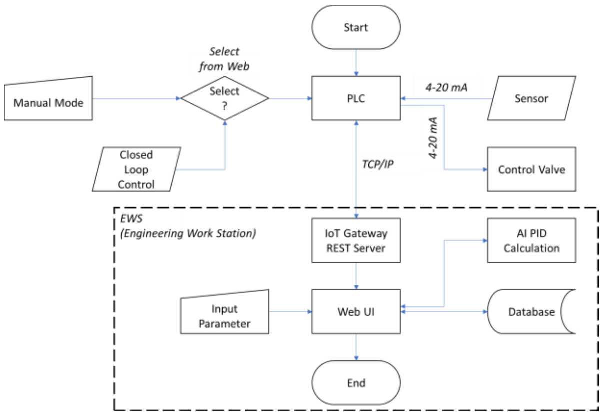

Figure 2. Flow chart process

At Level 0 of the ISA-95 hierarchy (Field Device Zone), physical devices directly interact with the industrial process. As illustrated in Figure 3, the process water is pumped into the tank (TK-101) by pump PU-101. The liquid level inside the tank is continuously measured by the level transmitter (LT-101), which sends a signal to the level indicator controller (LIC-101). In this study, the LIC symbol represents the control function of the loop. However, the actual control is executed by the PLC, which implements the PID algorithm. Based on the measurement, the PLC adjusts the level control valve (LCV-101) to regulate the flow of process water, maintaining the tank level at the desired set point.

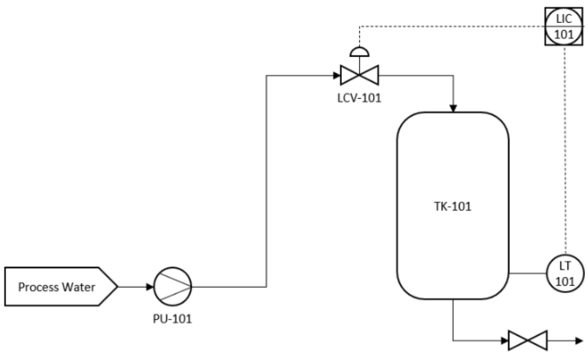

Figure 3. PID level control

At Level 1, a Programmable Logic Controller (PLC) serves as the central controller of the process and manages communication between sensors and actuators (control valves). The PLC interfaces with input and output devices using 4–20 mA hard-wired signals, while communication between Level 1 and Level 2 is established via Ethernet cable using the TCP/IP protocol. In this study, the ladder programming language is used to develop the PID level control logic, as well as to configure the sensor input and actuator output addressing at Level 0 (Field Device Zone). This configuration is illustrated in Figure 4.

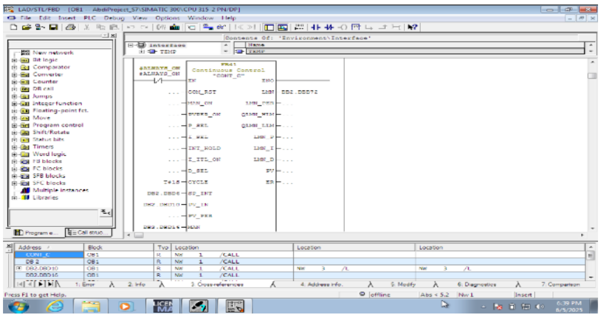

Figure 4. Program PID control

At Level 2, this study implements an interface that bridges the PLC with web or cloud-based applications using the TCP/IP protocol, enabling real-time read/write communication between the system and the PLC. Additionally, it provides a REST API (Representational State Transfer Application Programming Interface) to support external applications such as the web based User Interface (Web UI) and the AI based PID controller. This architecture is illustrated in Figure 5.

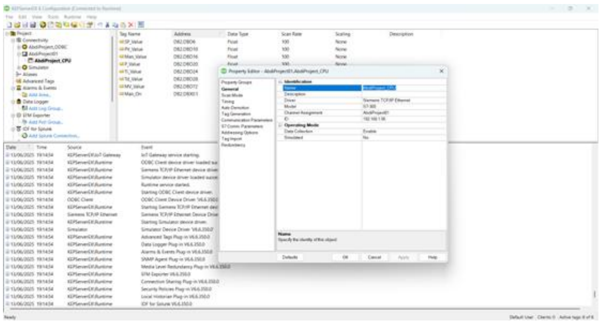

Figure 5. IoT gateway configuration

An IoT gateway application is utilized as the intermediary and provider of the REST API, enabling the transmission of data to and from the PLC to be routed through a REST server. The system uses the POST method to send data and the GET method to retrieve data from the REST server. This process is illustrated in Figure 6 and Figure 7.

```php
$ids_raw = isset($_GET['ids']) ? $_GET['ids'] : '';
$ids_array = explode(',', $ids_raw);
$query = implode('&ids=', array_map('urlencode', $ids_array));
$url = "https://127.0.0.1:39320/iotgateway/read?ids=" . $query;

$context = stream_context_create([
    "ssl" => ["verify_peer" => false, "verify_peer_name" => false]
]);

$json = file_get_contents($url, false, $context);
$data = json_decode($json, true);
echo json_encode($data);
```

Figure 6. GET method

```php
$id = $_POST['id'];
$v = floatval($_POST['value']);

$data = json_encode([["id" => $id, "v" => $v]]);
$options = [
    "http" => [
        "header"  => "Content-Type: application/json",
        "method"  => "POST",
        "content" => $data
    ],
    "ssl" => ["verify_peer" => false, "verify_peer_name" => false]
];

file_get_contents("https://127.0.0.1:39320/iotgateway/write", false, stream_context_create($options));
```

Figure 7. POST method

At Level 3, the system functions as a data historian or central data repository that receives data from Level 2. It stores sensor log data, input parameters, output values, and PID parameters. This layer enables data analysis, trend visualization, and performance evaluation of the control system. The architecture is illustrated in Figure 8.

id	PV_Value	SP_Value	MV_Value	P_Value	Ti_Value	Td_Value	Man_On	Time
17073	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:34
17072	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:33
17071	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:32
17070	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:31
17069	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:30
17068	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:29
17067	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:28
17066	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:27
17065	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:26
17064	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:25
17063	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:24
17062	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:23
17061	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:22
17060	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:21
17059	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:20
17058	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:19
17057	34.0625	35	52.3875008	2	20000	10000	0	2025-06-10 22:17:18

Figure 8. Historical data

2.2 Transfer Function of Control Valve LCV-01

The control system used in this study is represented by an LIC (Level Indicator Controller) loop with a control valve labeled LCV-01. In practice, the control function is fully executed by the PLC, which performs the PID algorithm and generates an analog output signal of 4–20 mA, corresponding to a valve opening range of 0–100%. The LCV-01 is configured as a Fail-to-Closed valve, meaning that in the event of a system failure, the valve will automatically shut to prevent uncontrolled inflow. This configuration is part of the Safety Instrumented System (SIS), ensuring protection of the surrounding process area from potentially hazardous conditions.

The system exhibits a linear response to step input changes. A step change from 0% to 100% input results in a linear output response from 0% to 100% within 8 seconds. The system is assumed to be inertia-free, with no delay and no saturation.

The step input is normalized from 0 to 1 (unit step), and the output is also normalized from 0 to 1 (100%). Therefore, the input-output transition can be represented as follows:

$$\Delta\mu(t) = 1 \tag{1}$$

$$\Delta y(t) = 1 \tag{2}$$

$$y(t) = K \cdot t \tag{3}$$

The output increases linearly over time, with K representing the rate of change of the output with respect to time. Based on the given data that y(8) = 1, the system response can be expressed as :

$$1 = K \cdot 8 \Rightarrow K = \frac{1}{8} = 0{,}125 \tag{4}$$

$$y(t) = 0{,}125 \cdot t \tag{5}$$

To obtain the transfer function *G(s)*, the Laplace Transform is applied to both the input and output of the system:

$$\mathcal{L}\{u(t)\} = U(s) = \frac{1}{s} \quad (6)$$

$$\mathcal{L}\{y(t)\} = \mathcal{L}\{0{,}125 \cdot t\} = \frac{0{,}125}{s^2} \quad (7)$$

$$G(s) = \frac{Y(s)}{U(s)} \quad (8)$$

$$G(s) = \frac{0{,}125/s^2}{1/s} = \frac{0{,}125}{s} \quad (9)$$

This model indicates that the system behaves as a pure integrator with a gain of K = 0,125. In this case, the system output increases by 0,125 units per second in response to a unit step input. This characteristic is illustrated in **Figure 9**.

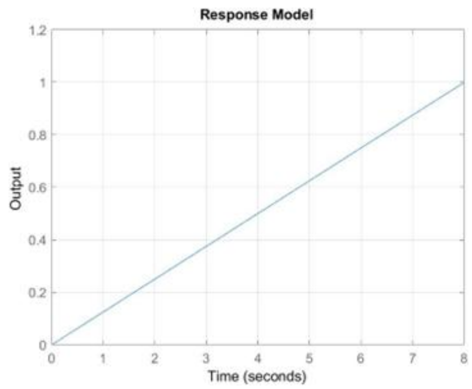

Figure 9. Mathematical modeling of transfer function

3 Results and Discussion

The implementation results of the Web Based SCADA system designed in this study demonstrate that the integration of the PLC, SCADA interface, and PID parameter optimization using the Firefly AI algorithm can operate in real-time and efficiently in controlling the liquid level control system using the LCV-01 valve.

Testing results show that the Firefly algorithm produces more stable and faster control compared to manual tuning and the Ziegler–Nichols method. This is illustrated by the mathematical modeling results shown in Figure 10.

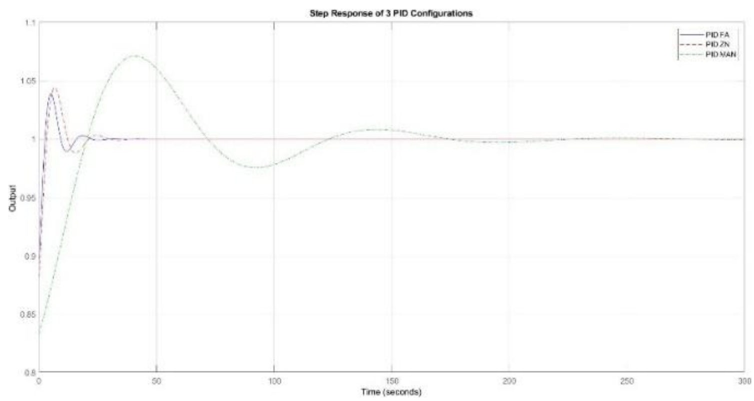

Figure 10. Comparison using mathematical modeling (AI Firefly, Ziegler–Nichols, Manual Tuning)

Figure 11. Firefly Algorithm

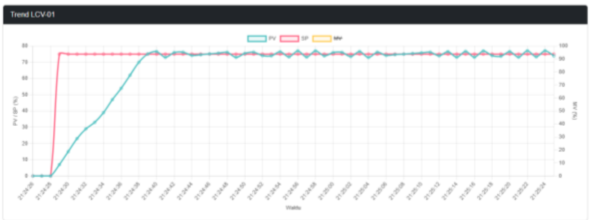

Figure 12. Ziegler Nichols

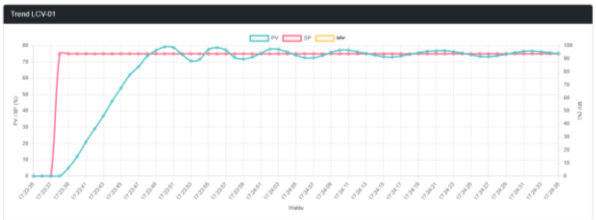

Figure 13. Manual Tuning

Based on the experimental results shown in Figure 11 (Firefly Algorithm), Figure 12 (Ziegler–Nichols), and Figure 13 (Manual Tuning), the performance comparison of each tuning method is summarized in Table 1**.** Table 1 presents a comparative analysis of the system performance using Firefly Algorithm, Ziegler Nichols, and manual tuning methods. It can be observed that the Firefly Algorithm achieves the fastest rise time (9 seconds), the lowest overshoot (3%), and the shortest settling time (11 seconds). In contrast, Ziegler–Nichols and manual tuning result in longer settling times and higher overshoot values, indicating less efficient control performance.

Table 1. Comparative results of PID tuning methods

PID	Rise Time	Overshoot	Settling Time	Kp	Ti	Td
Firefly Algorithm	9 Seconds	3%	11 Seconds	30	1.5s	2.3s
Ziegler Nichols	11 Seconds	4%	20 Seconds	20	2s	3s
Manual Tuning	11 Seconds	7%	40 Seconds	2	10s	20s

Based on the data above, the Firefly algorithm demonstrates superior performance in minimizing overshoot and reducing settling time. This finding is consistent with the studies by Altbawi et al. [1], Li et al. [13], and Ali and Rahman [8], which confirmed that the Firefly Algorithm can produce a more efficient control system compared to conventional methods.

The Web Based SCADA system developed in this study offers flexibility, as it can be accessed from various devices without the need for special installations. This aligns with the findings of Chen et al. [6], Nguyen et al. [10], and Santos et al. [16]; however, the present study adds layers of artificial intelligence and PID optimization into the control system—an aspect that has not been addressed in previous research. This enhancement is illustrated in Figure 14 and Figure 15.

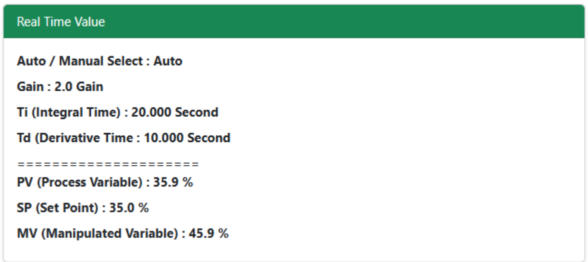

Figure 14. Realtime Value on Web Page

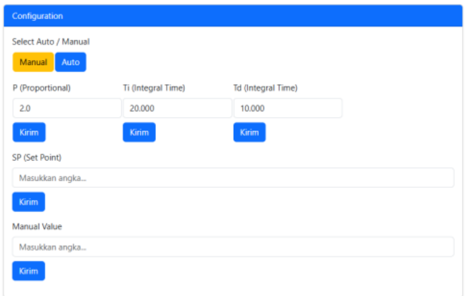

Figure 15. Input Parameter on Web Page

Additionally, the Web Based SCADA system demonstrates a page load processing time of approximately 61 milliseconds, as shown in Figure 16.

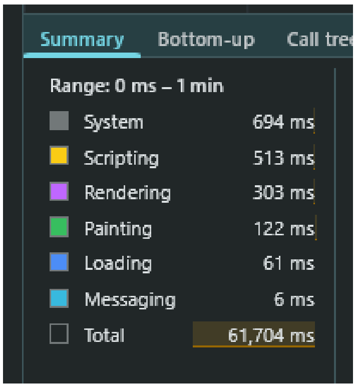

Figure 16. Time to Load Page

This study also integrates SCADA Layers 1 through 3 in accordance with the ISA-95 standard—starting from data acquisition via PLC (Layer 1), supervision through the IoT Gateway and SCADA interface (Layer 2), up to control management and AI-based analysis at Layer 3. This multi-layer integration approach is rarely found in previous studies and demonstrates a systemic strategy in industrial control architecture.

One of the key advantages of the Web Based SCADA system developed in this study is its ability to provide data trending, both in real-time and as historical process trend graphs. This feature enables operators to monitor variables such as the Process Variable (PV) and Set Point (SP) live, without needing to refresh the web page. Other notable advantages include:

- Performance analysis of the control system over time.
- Data storage and export capabilities from the database, facilitating auditing and data-driven decision-making.

These features further strengthen the position of the Web Based SCADA as a flexible and intelligent platform, which not only controls the process but also visualizes and analyzes it comprehensively. The developed SCADA system can be accessed via standard web browsers on multiple devices, without requiring special software. Control visualizations, trend charts, and parameter inputs are accessible by multiple users, enhancing operational efficiency.

Table 2. Operational Effectiveness Comparison

Aspect	Conventional SCADA	Web Based SCADA
Software License	High cost, proprietary license required annually	No license, browser-based with open-source support
Hardware Requirement	Dedicated SCADA workstation and specialized HMI	Standard PC, laptop, or mobile device
Installation & Maintenance	Complex setup requires vendor support	Simple deployment, no additional installation
Tuning Effort	Manual trial-and-error, time-consuming	Automated PID optimization via Firefly Algorithm
Downtime Impact	Higher due to repeated manual retuning	Reduced due to adaptive and self-optimizing PID
Overall Operational Cost	High operational and maintenance expenses	Significantly reduced operational costs

The cost-effectiveness of the proposed Web Based SCADA system is evident when compared with conventional SCADA platforms, as summarized in Table 2. Conventional SCADA systems typically require expensive proprietary licenses and dedicated hardware, resulting in higher capital and operational costs [6], [10], [16]. In contrast, Web Based SCADA solutions leverage standard devices and browsers, eliminating the need for costly installations and reducing long-term maintenance expenses [4], [16].

Moreover, manual PID tuning in traditional systems is time-consuming and often introduces performance inconsistencies, leading to additional downtime [2], [12]. By integrating the Firefly Algorithm, tuning becomes automated and adaptive, which reduces the need for frequent operator intervention and minimizes production losses [1], [8], [13], [19]. These findings confirm that the system is not only technically efficient but also economically advantageous, providing measurable reductions in both capital and operational expenditures.

4 Conclusion

A Web Based SCADA system was successfully designed and implemented to control a closed-loop process using a PID controller integrated with a PLC and optimized through Artificial Intelligence (AI). The developed web interface enables real-time monitoring and control without requiring specialized software installation, ensuring accessibility across multiple devices. Communication between the Web Based SCADA system and the PLC was established reliably via the TCP/IP protocol, allowing accurate data exchange for both reading and writing process variables.

The integration of the Firefly Algorithm for PID parameter optimization (Kp, Ti, Td) significantly improved control performance compared to conventional tuning methods, as demonstrated by experimental testing. The system achieved faster rise time, reduced overshoot, shorter settling time, proving the effectiveness of AI-driven optimization in enhancing closed-loop control.

In addition, the system successfully visualized real-time process data and enabled operators to adjust parameters directly through the web interface. Beyond technical performance, the web-based architecture also shows potential cost-effectiveness, since it reduces the dependency on expensive proprietary SCADA software and dedicated hardware, and simplifies installation and maintenance. This makes the proposed system not only a practical and flexible solution, but also an intelligent solution for modern industrial automation.

5 Acknowledgment

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6 References

[1] Altbawi, S. M. A., et al. "Tuning of PID Controller Using Hybridized Modified Firefly-Chaos Optimization Algorithm." *International Journal of Intelligent Systems and Applications in Engineering*, vol. 9, no. 3, pp. 2224–2230, 2021.

[2] Rustamova, S., and F. Rustamov. "Problems of Integrating Artificial Intelligence with SCADA Systems." *International Journal of Energy Applications and Technologies*, vol. 10, no. 2, pp. 123–130, 2023.

[3] Irawan, D., Syah, S. A. A., & Cahyani, D. O. "Tuning PID Controller Berbasis Algoritma Kecerdasan Buatan." *Multitek Indonesia: Jurnal Ilmiah*, vol. 18, no. 1, pp. 72–82, 2024.

[4] Zhang, Y., et al. "AI-Enhanced SCADA Systems: A Review of Trends and Future Directions." *IEEE Access*, vol. 11, pp. 105344–105361, 2023.

[5] Kumar, R., & Singh, A. "Metaheuristic Algorithms for PID Tuning in Industrial Applications." *Journal of Control Engineering and Applied Informatics*, vol. 25, no. 2, pp. 33–44, 2023.

[6] Chen, L., et al. "Implementation of Cloud-Based SCADA Systems for Smart Manufacturing." *Sensors*, vol. 21, no. 18, 2021.

[7] El-Hawary, M. E., & Ahmed, K. "Digital Twin-Enabled Web-Based SCADA Systems." *IEEE Transactions on Industrial Informatics*, vol. 18, no. 12, pp. 8921–8932, 2022.

[8] Ali, H., & Rahman, M. "An Improved Firefly Algorithm for Nonlinear PID Controller Tuning." *Applied Soft Computing*, vol. 136, 2023.

[9] Singh, P., et al. "PLC-SCADA Integration with IoT for Smart Industrial Control." *International Journal of Electrical and Computer Engineering*, vol. 14, no. 1, pp. 55–63, 2024.

[10] Nguyen, T., et al. "Web-Based Supervisory Control Systems in Industry 4.0." *Journal of Industrial Information Integration*, vol. 30, 2022.

[11] Suryawan, A., et al. "Optimization of PID Controller Parameters Using Firefly Algorithm in Temperature Control System." *Journal of Physics: Conference Series*, vol. 1869, 2021.

[12] Prakash, J., & Verma, A. "Artificial Intelligence for SCADA Data Analytics." *IEEE Access*, vol. 12, pp. 55422–55433, 2024.

[13] Li, X., et al. "Hybrid Firefly Algorithm for Robust PID Control in Power Systems." *Energies*, vol. 15, no. 6, 2022.

[14] Ghosh, A., & Banerjee, S. "Advances in SCADA for Industrial Automation Using AI." *International Journal of Automation and Smart Technology*, vol. 13, no. 4, pp. 281–292, 2023.

[15] Zhang, J., & Zhao, Y. "Adaptive PID Tuning via Firefly Algorithm in Cyber-Physical Systems." *Frontiers in Control Engineering*, vol. 5, 2024.

[16] Santos, M., et al. "Web-SCADA with Cloud and Edge Computing Integration." *IEEE Internet of Things Journal*, vol. 10, no. 7, pp. 5990–6001, 2023.

[17] Wang, H., et al. "Data-Driven SCADA System Design for Process Optimization." *Computers & Chemical Engineering*, vol. 162, 2022.

[18] Kumar, S., et al. "IoT and AI-Based PID Tuning for Industrial Control." *International Journal of Electrical Power & Energy Systems*, vol. 140, 2022.

[19] Rahman, M., et al. "AI-Based Optimization Algorithms for PID Control in Industry 4.0." *Applied Sciences*, vol. 14, no. 2, 2024.

[20] Yilmaz, B., et al. "Real-Time Web-Based SCADA with Machine Learning Integration." *Journal of Industrial Engineering International*, vol. 19, pp. 421–432, 2023.

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