Jurnal Teknologi dan Manajemen

ISSN (Print) 1693-2285 ISSN (Online) 2808-9995

Research Article

Miniature Furnace Temperature Monitoring System Using Wireless-Based Resistance Temperature Detector Sensor

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ARTICLE INFO

Received : 03 July 2024
Accepted : 29 August 2024
Published : 03 September 2024

KEYWORDS

Furnace, Monitoring System, Temperature Sensor, Resistance Temperature Detector, Wireless Communication.

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A B T R A C T

PT. GCNS in Morowali, which produces NPI (Nickel Pig Iron), has a furnace area of the Ferronickel Department for melting raw ore materials into NPI. In this area, there are many sensors, one of which is the RTD sensor, which is used to measure temperature in various processes in the furnace system. Through the observation, problems were found related to replacing damaged sensors because these sensors still use cables in pipes with complicated and long paths. So that during the sensor maintenance process, it is necessary to check and dismantle the complicated cable paths in the pipes, resulting in the production process stopping in the furnace for a long time. This study implemented a sensor system that uses NodeMCU ESP8266 as a wireless device that functions as a data sender and receiver module from the RTD sensor, which is integrated with the PWM to voltage and voltage to current converter module so that the sensor reading data can be integrated with the 4-20 mA analog input on the PLC. So, wireless sensors can eliminate complicated wiring systems and save more time during maintenance. The test results on Sensors 1, 2, and 3 have an average difference value of 0.36, 0.53, and 0.59, respectively. The percentage of errors produced respectively are 0.68%, 1.162%, and 1.21%; the occurrence of error values in the testing process is due to the accuracy of the NodeMCU used of 10 bits, or 4 mV for every 1 decimal change.

INTRODUCTION

In the field of instrumentation and control, temperature sensors are employed to identify variations in temperature. There exist various types of these sensors such as thermocouples, Resistance Temperature Detectors (RTDs), LM35, and thermistors, each possessing unique characteristics. Among these, the RTD PT100 is the most commonly utilized temperature sensor in industrial applications. (N. Ayuningdyah et al., 2021).

Temperature monitoring is essential across numerous sectors, and it relies on data storage and analysis. Web-based temperature monitoring functions as a specialized tool for recording temperatures, tracking room conditions, storing data in a database, and providing real-time temperature updates on a website via a web server (C.K. Haroswati et al., 2010)

In the industrial area in Morowali, the Ferronickel Department of PT. GCNS (Guan Ching Nickel and Stainless Steel) produces NPI (Nickel Pig Iron), starting from wet ore and continuing through a long process until it reaches the molding process to become an NPI product. Almost every process involves hot temperatures. This temperature must always be monitored so that the ore is not damaged. The Ferronickel Department's furnace area is where ore is smelted. In this area, there are many sensors, one of which is the RTD sensor, which is used to measure temperature in various ore processing processes into NPI. For example, to measure the temperature of the furnace, cooling water that circulates around the furnace. Apart from measuring the temperature of the cooling water, RTD is also used to measure furnace temperature, where almost every part of the furnace is equipped with an RTD sensor. The results of the RTD sensor readings are sent using a cable to the temperature display 3 - 10 meters above it. When observations at the research location were conducted, we found problems related to replacing damaged sensors. The problem is that the sensors still use long cables in pipes that have complicated and long paths.

In temperature monitoring, a variety of hardware options have been utilized and improved upon, such as the Raspberry Pi (M. Fatangare et al., 2020) and PLC (A. Kaur et al., 2016).

(P. S. B. Macheso et al., 2021) The temperature monitoring system in the IoT-based industry, using NodeMCU ESP8266 E. S. Elsahwi et al., 2020) Existing temperature monitoring options tend to be expensive, often necessitating line-of-sight detection, use of electrical wiring, and requires backup electricity in the form of batteries. Their research introduces a self-sustaining temperature monitoring solution designed to wirelessly communicate with a local server within a facility. This is achieved through the use of a thermoelectric generator (TEG) and a burst-mode DC/DC converter, which together provide the necessary power for transmitting temperature data to operators.

(U.Y. Oktiawati et al., 2021) conducted research about monitoring system of furnace temperature. The developed system consists of three main elements: hardware, electronics, and software. The hardware includes components such as K-type thermocouple sensors, LM35 sensors, a power supply unit, and a protective case. In terms of electronics, an Arduino Mega 2560 served as the central microcontroller, supported by peripherals such as the MAX 6675. The software component facilitated data communication between the furnace and users via a graphical user interface (GUI). Programming for the Arduino was conducted using Arduino IDE, while the GUI was developed using Microsoft Visual Studio.

A method for measuring the temperature profile across zones in a horizontal tube furnace is introduced by (H. P. Tripathy et al. 2018). This system includes an ultrasonic transducer, quartz tube, resistive furnace, Arduino microcontroller, and a regression model based on relevance vector machines (RVM). The ultrasonic transducer is positioned to send and receive acoustic waves reflected from the resistive horizontal tube furnace.

Research about an innovative wireless temperature sensor using dielectric materials, utilizing high-Q cavities embedded in a three-dimensional photonic crystal (PhC) is conducted by (J. Sánchez-Pastor et al., 2023). The sensor detects changes in resonance frequency by monitoring variations in the dielectric properties of its material with temperature. It is manufactured using Lithography-based Ceramic Manufacturing in Alumina (Al_2O_3), and is designed to operate based on this principle.

(Y.Li et al., 2018) proposed a novel approach for determining the time constant of the thermocouple using an enhanced high-temperature furnace setup. This system utilized a high-temperature furnace to create a stable temperature environment, alongside a rapid feed mechanism to insert the thermocouple into the furnace and induce temperature ramp excitation. The furnace could achieve temperatures up to 1500 °C, with a temperature uniformity error of ±1°C in the field.

Then, (J. Sulistyo et al., 2021) conducted research using a type K thermocouple sensor to measure the temperature in muffle type furnace. Because the K type thermocouple is a delicate sensor and requires an amplifier that includes built-in cold junction compensation, this research uses a MAX6775 amplifier module. The sensor reading results are then displayed via an IoT platform named Thingspeak. Data processing in this research uses Arduino IDE before sending data wirelessly using NodeMCU.

Based on the informations that gathered above, we cannot find solution regarding the problems we found at the research location, which all use sensors with the Resistance Temperature Detector or RTD type. So, in this research, a communication system was built between the sensor and the RTD which reads the temperature in the furnace with a display displaying the sensor reading values wirelessly. Apart from designing the communication system, the display of sensor readings on the website was also designed. It is hoped that the results of this research will make it easier for the maintenance team to replace damaged sensors without having to check and dismantle complicated cable paths in pipes and to reduce the use of cables in the furnace area.

METHOD

Observations and research were conducted in the furnace area of the Ferronickel Department, PT. Guang Ching Nickel and Stainless Steel in Morowali Regency.

Fig. 1. Furnace Area, Ferronickel Departement. PT. GCNS

The designed system uses a NodeMCU ESP8266 microcontroller in the client block to send data from RTD

 DOI: 10.52330/jtm.v22i2.317

sensor readings. Data from the client block will be received by another NodeMCU ESP8266 microcontroller in the server block. The block diagram of the designed system is shown in the figure below:

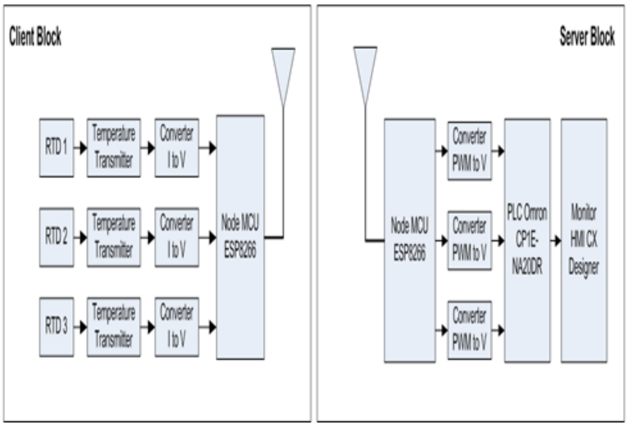

Fig. 2. System's Diagram Block

The RTD sensor detects the temperature in the furnace, then the RTD sensor output is converted into current using a transmitter. In order for the transmitter to work, a 24 VDC supply is required, then the transmitter output in the form of a current with a range of 4mA - 20mA will be converted into voltage using an I to V converter before being sent by the Node MCU ESP8266 to the client block wirelessly. The data will be reprocessed into voltage when received by the NodeMCU ESP8266 on the server block. This is because the output of the data generated by the NodeMCU ESP8266 is in the form of PWM. Then, the data that has been converted into voltage will become an analog input on the Omron CP1E-NA20DR-A PLC, which is used before being displayed as an HMI display on the monitor.

In designing a wireless-based monitoring system, the first thing to be created is a module that reads and sends data from the sensor (client) and a module that will receive data sent from the client (server).

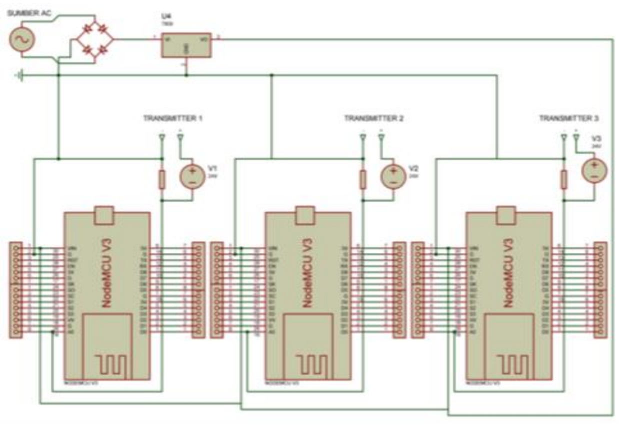

Fig. 3. Client's Circuit Block

The client circuit is a circuit that converts the output current from the transmitter into voltage using a 250 Ω resistor, then the data is sent to the server circuit. The client module circuit is a circuit that will read data from the temperature sensor and then send it to the server module circuit. In the client module, there is a circuit that converts current into voltage using a resistor and a power supply circuit for the NodeMCU ESP8266 microcontroller.

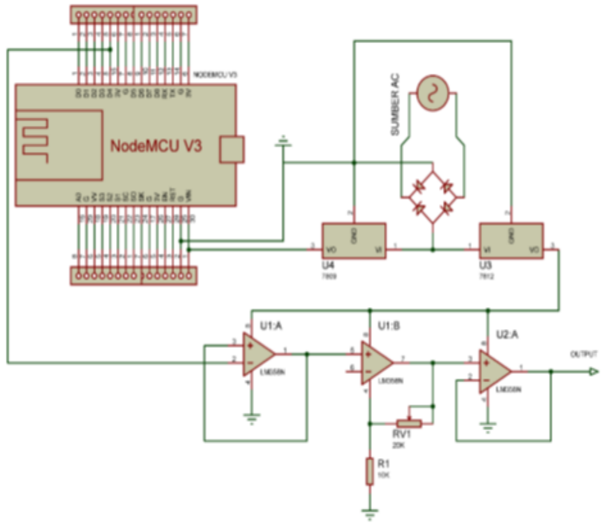

Fig. 4. Server's Circuit Clock

The server circuit in the server block is a circuit that creates an access point so that it can be accessed by the client, so that interaction can occur between the client and the server, while also receiving data from the client.

In coding the NodeMCU ESP8266 program, Arduino IDE software is used. In this study, the NodeMCU ESP8266 which acts as a server, is able to create its own access point and can be accessed by other NodeMCU ESP8266, which acts as a client by setting the IP address in the coding program to be the same as the IP given by the server. Using the NodeMCU ESP8266, data transmission from sensors can be done wirelessly.

Fig. 5. Program for Client

The coding program for the client block is shown in Figure 5. While the coding program for the server block is shown in Figure 6.

Fig. 6. Program for Server

After the components on the PCB are installed and soldered, the circuit is tested by measuring the output voltage using a multimeter and observing the signal waveform with an oscilloscope. The voltage is only checked in the client circuit to see if it matches the expected input and output. While in the server circuit, in addition to checking the voltage, it is also necessary to check the output waveform of the circuit using an oscilloscope to find out if the PWM circuit is working properly. The following is an image of the output waveform produced by the circuit in the server circuit.

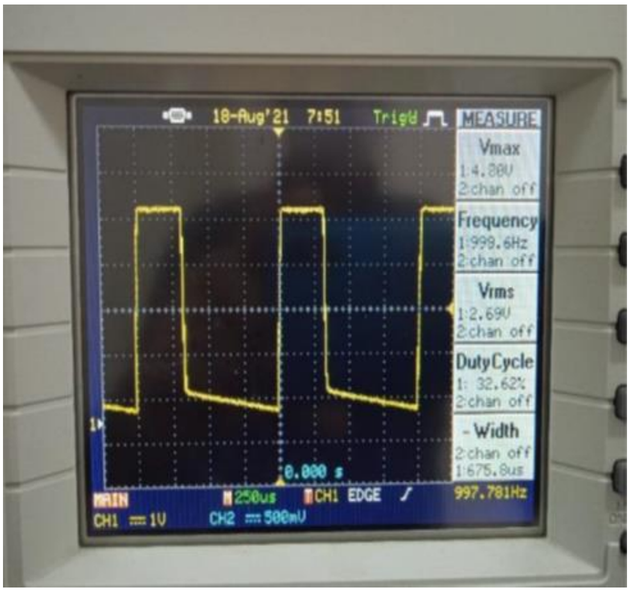

Fig. 7. Output Wave from Server's Circuit

Software and circuit integration is done by uploading the program to the NodeMCU ESP8266 microcontroller that has been installed on the client and server modules. If there are no errors, the software and circuit testing can continue. Software and circuit testing can be successful if the client module can read and send data wirelessly via an access point. Then the server module receives and displays the data on the serial monitor.

RESULT AND DISCUSSION

The client module is a circuit that will read data from the temperature sensor and then send it to a series of server modules. In the client module, there is a circuit that converts current to voltage using a resistor and a power supply circuit for the NodeMCU ESP8266 microcontroller. The client module panel is shown in Figure 8.

Fig. 8. The Result of Client Modul

To convert current into voltage, a resistor with a value of 250 Ω is required. The use of this resistor value is to obtain an output from the RTD transmitter of at least 4 mA and a

 DOI: 10.52330/jtm.v22i2.317

maximum of 20 mA, which is a universal standard in industrial automation.

The server module panel consists of a power supply circuit and a voltage amplifier circuit, as shown in Figure 9.

Fig. 9. The result of Server Modul

The server module is a circuit receiving data from the client module. Then, the output of the server module circuit is programmed to come out on one of the PWM pins of the NodeMCU ESP8266. The PWM output is amplified first before being converted into voltage to obtain the desired voltage. For this reason, the server module has a voltage amplifier circuit in the form of an Op-Amp circuit to obtain a maximum output voltage of 5 V.

Sensor calibration is needed to determine whether the sensor works properly. The method used to calibrate the sensor is by comparing the results of the sensor readings by the Thermo Gun measuring instrument with the sensor temperature values on the serial monitor.

The first sensor is placed at the base of the mini furnace. The difference between the ThermoGun readings and the display on the serial monitor is presented in graphic form in Figure 10.

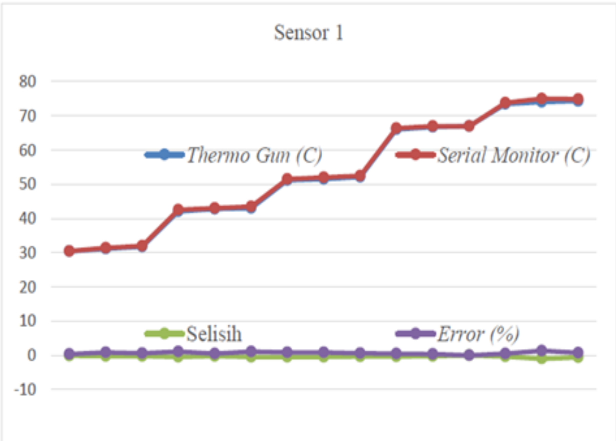

Fig. 10. Sensor 1 Chart Comparison

Based on the comparison data between the measurement results using ThermoGun with the reading data displayed on the serial monitor, it was found that on Sensor 1 the average difference value was 0.36 with 15 data collection times. So that the error value was obtained as much as 0.68.

Fig. 11. Sensor 2 Chart Comparison

Comparing the measurement results using ThermoGun with the reading data displayed on the serial monitor, it was found that on Sensor 2, the average difference value was 0.53, with 15 data collection times. So that the error value was obtained to be as much as 1,162.

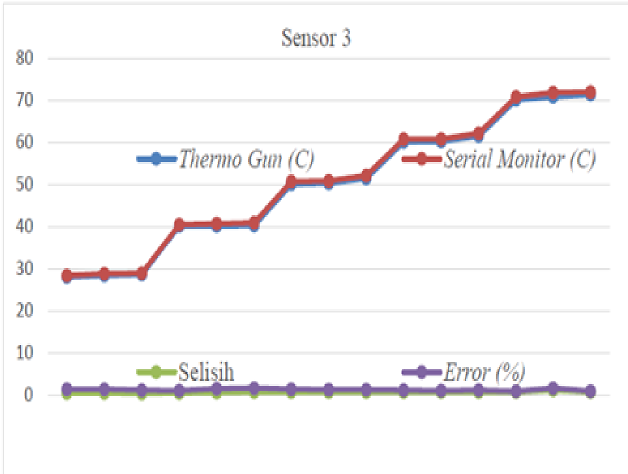

Fig. 12. Sensor 3 Chart Comparison

Based on the comparison data between the measurement results using ThermoGun and the reading data displayed on the serial monitor, it was found that on Sensor 3, the average difference value was 0.59, with 15 data collection times. So that the error value was obtained as much as 1.21.

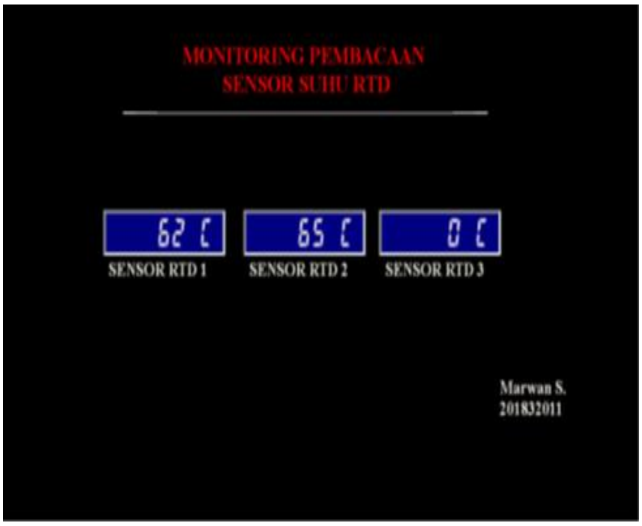

Fig. 13. HMI Display in Serial Monitor

To create an HMI display on the serial monitor, CX Designer is used which supports the Omron CP1E-NA20DR-A PLC device used in this study to read output voltage data from the server module. The designed HMI display can be seen in Figure 13 above.

CONCLUSION

Based on the design, implementation, and testing results of the hardware and software system data, the RTD sensor reading results can be integrated with the Node MCU ESP8266 on the client system via the transmitter and Current to Voltage converter so that it becomes an analog voltage data that can be processed and processed by the microcontroller. Then, the sensor reading results can be sent wirelessly from the client module to the server module. Wireless data processing and sending is sufficient using the Node MCU ESP8266. On the server system, the data is processed into PWM data, which is then converted into analog voltage data via the PWM to Voltage converter so that it can be processed by the Omron CP1E-NA20DR PLC via analog I/O. Data from the PLC is displayed on the monitor using the HMI CX Designer software. For the test results, there is a difference that is not too significant, namely if averaged from 15 temperature data samples for sensor 1 of 0.36 ° C or an error value of 1.16%, sensor 2 of 0.53 ° C or an error value of 0.7%, and for sensor 3 of 0.59 ° C or an error value of 1.21%. The occurrence of error values in the testing process is due to the accuracy of the NodeMCU used of 10 bits, or 4 mV for every 1 decimal change.

This research test is still being carried out on a mini furnace prototype. With the success of sending data wirelessly, this research will be applied to the Electric Arc Furnace. Then if in this study we still use 3 ESP8266 Node MCU units on the client block (1 ESP8266 Node MCU for 1 sensor), we will use one ESP8266 Node MCU unit for several sensors with a multiplexer system.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.
Funding: “This research received no external funding”.
Acknowledgment: The author team would like to convey the Metal Industry Polytechnic of Morowali, especially the Electrical and Installation Engineering study program and also the company, PT. Guang Ching Nickel and Stainless Steel, especially the Ferronickel Department, which provided the author team with the opportunity to carry out this research.
Conflicts of Interest: “The authors declare no conflict of interest.”

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DOI: 10.52330/jtm.v22i2.317