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CERAMIC FIRING TEMPERATURE TRAJECTORY MONITORING SYSTEM ON IOT-BASED GAS FURNACE

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Abstract
This study introduces a novel system where a conventional ceramic furnace is upgraded with IoT capabilities, specifically utilizing NodeMCU and a thermocouple sensor. The integrated system enables real-time temperature monitoring, facilitating the correction of firing trajectory errors in the ceramic firing process. The sensors reading minimizes errors by detecting temperature changes with a maximum deviation of -2.5 °C and a minimum deviation of -1 °C. The average error ranges from 1.81% to 3.79%. The collected data is seamlessly transmitted to Google Spreadsheet for online monitoring. This comprehensive solution not only minimizes recording errors but also ensures the quality of final ceramic products by preventing issues such as cracks, breaks, black cores, and non-uniform sizes. The incorporation of NodeMCU, thermocouple sensors, and online monitoring represents a significant technological leap in optimizing ceramic firing processes for heightened precision and efficiency.

Keywords : Internet of Things, Ceramic Firing, Thermocouple Sensor, Monitoring System.

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INTRODUCTION

Ceramics product is importance in our daily life [1], [2]. Based on the firing process, Ceramics with a firing process of 900 °C - 1000 °C clasified as earthenware ceramics, while ceramics with a firing process at 1200 °C - 1400 °C clasified as stoneware ceramics [3], [4]. The firing process of ceramics will make them harden and become able to hold water [5]. Even though the firing process is important, the ceramic industry in Indonesia still relies heavily on human power to control the firing so that errors often occur and cause product defects [3]. Therefore, realible temperature monitoring technology for the firing process in ceramic production is needed to avoid unsuitable end products and to improve product quality [6].

Many researchers have conducted research on temperature monitoring or measurement. In reference [7] shows that a study using the LM35 sensor with an Arduino Uno microcontroller by obtaining temperature results displayed on the LCD screen using pin A1 hardware with the help of analogue pins using pulse width modulation (PWM). Another study also show that K-type thermocouple sensors could be use to prevent the expansion of the bottle used due to being filled with water with high temperature [8].

The rapid development of technology over time has encouraged progress in many aspects of life, one of which is in the field of information technology. Data transmission technology is one of the rapidly developing technologies, where this technology is able to send data quickly and cheaply. The development of this trend supports the development of methods between one device and another through the internet network, this technology is known as the Internet of Things [9]. The existence of IoT can provide many opportunities for unlimited development in the business world. IoT has great potential to be applied in various types of business industries [10]. The Internet of Things works by utilising a programming argument where each command argument produces an interaction between machines that are connected automatically without human intervention and at any distance. The Internet is the link between the interaction of these machines, while humans are only in charge of regulating and supervising the operation of the tool directly [11].

This research aims to overcome the problem of temperature monitoring in the ceramics industry by developing an IoT-based temperature monitoring system. This system will consist of a monitoring system for tracking ceramic firing temperatures in gas furnaces using wireless sensors and recording the firing process in real time. By creating an IoT-based firing route temperature monitoring system it can be evidence of whether the firing process is running well and prevent defects in ceramic products.

METHOD

The method used in this research is quantitative data, the data directly collected as primary data source in this research from the application of temperature monitoring system hardware which developed for ceramic firing. First, a literature study was carried out by collecting ceramic firing data and firing routes from several sources such as books, journals, observations and survey approaches. The next stage is to design a system block diagram concept for monitoring firing trajectories. Next is collecting the tools and materials used. Then assembling the tools and materials according to the design. The system then tested at a ceramic gas furnace to evaluate it performance.

Figure 1 showing the work flow of the Internet of Things Method that will be applied to the design of the Ceramic Firing Temperature Path Monitoring System.

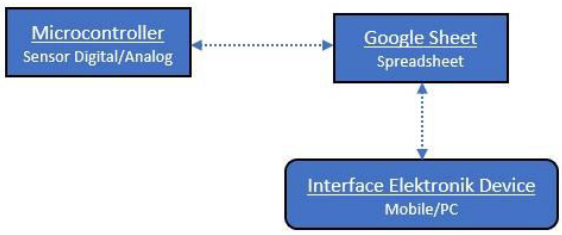
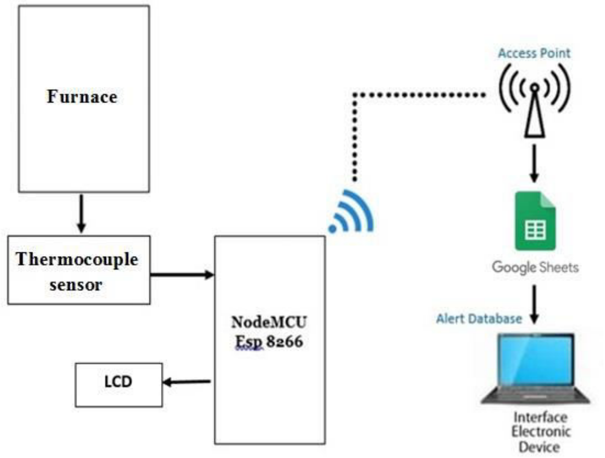


Figure 1. System Workflow

Figure 2 shows the system block diagram in the developed monitoring system. This system uses a K-type thermocouple sensor as a temperature sensor which is placed in the furnace. The K-type thermocouple will detect the temperature in the furnace in the form of a changing voltage, transmitted to the MAX31855 module then giving a signal to the NodeMCU, the changing voltage obtained from the sensor will be processed by the controller in the MCU. The data that has been taken will be connected to Google Spreadsheets then it will be read on the web interface.



Figurer 2. System Block Diagram

A. Electronic Components

Electronic components are supporting components of an electronic circuit which can work according to its usefulness, as for the use of components in system design, namely:

1) Microcontroller (NodeMCU ESP 8266-12E)

   A microcontroller is a functional computer system on a chip. Inside there is a processor core, memory and input output equipment [12]. NodeMCU ESP 8266 is a module consisting of NodeMCU and ESP 8266 microcontroller. In this board, NodeMCU and ESP 8266 are directly placed in one place so that we don't need to buy them separately or assemble them again, ESP8266 is designed so that Wifi is integrated directly, so ESP8266 does not require a Wifi module [13].

   ESP8266 itself is produced by the Espressif company and has a 32-bit L106 processor with RISC architecture. NodeMCU also has a C++ firmware base so that it can adapt to the Arduino IDE. NodeMCU ESP 8266 requires power around 3.3v - 5v, Access Point and Both (both) with three wifi modes namely Station. This module can stand alone without using any microcontroller because it already has equipment like a microcontroller. This module is also equipped with a processor, memory and GPIO.

2) MAX31855 Module

   MAX31855 is an excellent digital output conversion tool forof an excellent thermocouple with a 14-bit ADC built in

[14]–[16]. Serves to measure the output of a K-type thermocouple that provides measurement results to the microcontroller via *Serial Peripheral Interface (*SPI).

3) K-type Thermocouple
Thermocouples function to convert the heat difference in the measured object into a change in potential or voltage [17]. Thermocouples are temperature sensors formed from two different types of metals and the ends of the two metals are glued together. In thermocouples, the terms hot-junction and cold-junction are known. Hot-junction serves as a measurement point, while cold-junction serves as a reference point. Cold-junction can be connected to a heat source with a temperature of 0°C or connected to an electronic circuit to compensate for the 0°C temperature. If the thermocouple connection is exposed to heat, a Seebeck voltage will arise which is a function of the relationship between temperature and composition of the two metals [18], [19].

4) LCD (Liquid Cristal Display)
LCD is a type of media used to display information that uses liquid crystals as the main viewer. LCD controller in the module there is a microcontroller that functions as a controller for LCD character display. The microcontroller in an LCD is equipped with memory and register.

5) I2C (Inter Integrated Circuit)
I2C/TWI LCD 1602 is a module that is used to reduce the use of legs in LCD. The IC allows the LCD to be controlled using only two pins, namely SDA (Serial Data) and SCL (Serial Clock) which send data information between I2C and the controller [20], [21].

6) 3.3V 5V Breadboard Power Supply Module.
Functioning to reduce the voltage from 12v to 5v. this module is used to provide power to the NodeMCU, MAX31855 sensor module and I2C LCD.

B. Programming

1) Arduino IDE
Arduino IDE was created from a programming language, namely the JAVA programming language. Arduino IDE already has a C/C++ library which is generally said to be wiring so as to make input and output operations easier. The development of arduino IDE from processing software was revised so that it turned into Arduino IDE only for programming using Arduino. Arduino IDE is a single programming language that is almost the same as the C language. The Arduino programming language has been continuously revised to make it easier for beginners to do programming. When distributed, the Arduino microcontroller IC has added a programme called bootlader which is useful for mediating the Arduino compiler with the microcontroller. There are many programming languages used to program microcontrollers of course, but in programming arduino used is the C language.

2) C Programming Language
The C language applies the concept of sequence, where the programme is executed line-by-line from top to bottom in sequence. If the user writes these other functions below the main function, then the prototype section must be written. This is to introduce the compiler to the list of functions that will be used in the programme. However, if the other functions are written above or before the main function, then there is no need to write the prototype section above it [22].

3) Wireless Sensor Network (WSN)
Wireless Sensor Network refers to a network of spatially dispersed and dedicated sensors that monitor and record the physical conditions of the environment and forward the collected data to a central location. WSN can measure environmental conditions such as temperature, sound, pollution level, humidity and wind.
Wireless Sensor Network is a technology that performs sensing, control and communication for environmental monitoring by physical measurement. WSN consists of several sensors and base stations that are implemented and can transmit data to each other using a wireless network [23].

C. Hardware Design

After determining the main components to be used and collecting tools and materials according to the planned specifications, the next step is to make a wiring diagram of the power supply and module.

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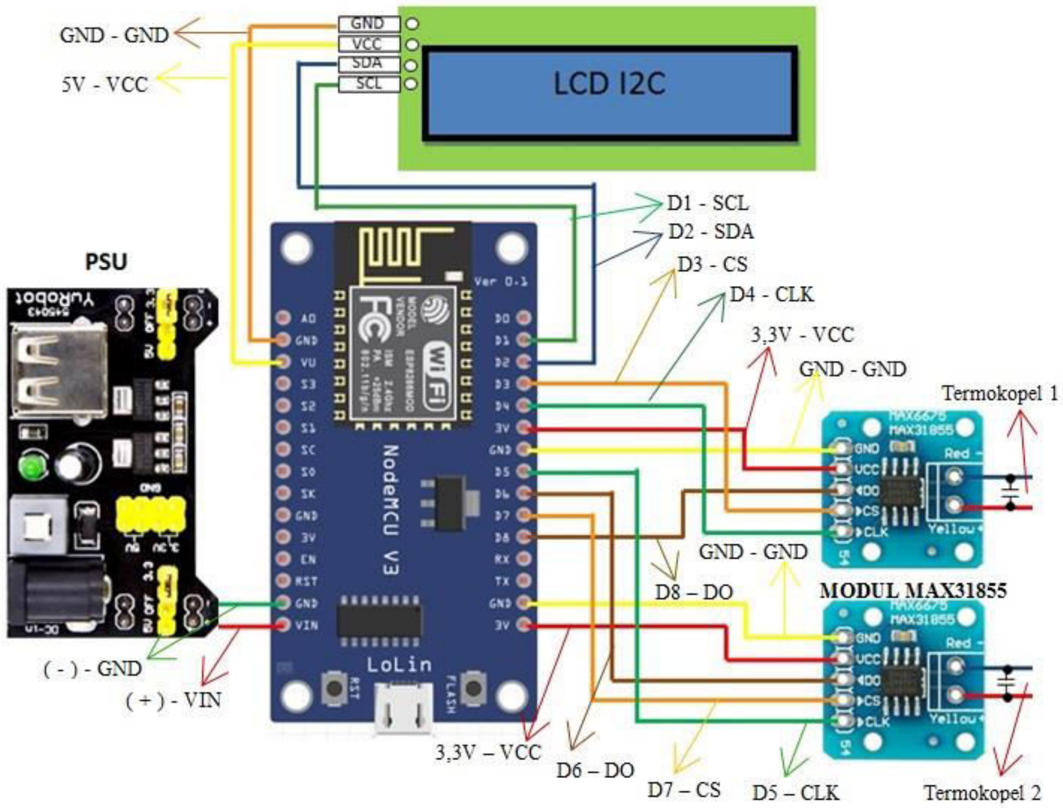

Figure 3. Wiring Diagram of Monitoring System

This system uses NodeMCU ESP8266 as a microcontroller for data transmission to the IoT system. For input using a K-type thermocouple with output using an I2C LCD to display the firing temperature monitoring results read by the thermocouple sensor that has been converted using the MAX31855 module. Figure 3 shows the wiring diagram used in the system

RESULT AND DISCUSSION

A. Electronic Component Assembly

The following are the results of assembling the entire system by connecting all the components according to the design using a hollow PCB measuring 7 x 10.5 cm to connect all the electronic components. The PSU is connected to the NodeMCU as a power source for the NodeMCU, MAX31855 module and LCD. The thermocouple sensor is connected to the MAX31855 module using a special cable for thermocouples. All installed electronic components are shown in Figure 4 All components are installed in the PCB box as a casing and LCD to display the temperature reading results as in Figure 5.

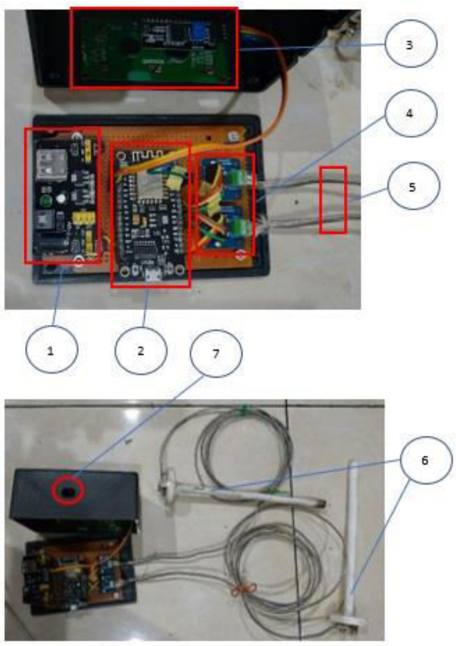

Figure 4. Monitoring System Module, (1) power supply, (2) nodeMCU, (3) lcd i2c, (4) max 31855 module, (5) thermocouple cable, (6) k-type thermocouple, (7) nodemcu port

Figure 5. LCD Panel Section

B. Programming Process

1. System Programming with Arduino IDE

This monitoring system is designed using NodeMCU ESP8266, requires the Arduino IDE application to do programming, after understanding the next flowchart is to change it in the form of language or programming code, forming the header section is the first thing to do in programming in the Arduino IDE, what is done is declaring the files that will be included in the program, especially in this case some libraries that need to be entered into the program according to the hardware used.

2. Google Sheet Programming

Programming on google spreadsheet is done to receive the data sent by NodeMCU ESP 8266 so it can be displayed in the spreadsheet and recorded automatically according to the specified time.

C. MAX31855 Sensor Test Rresult

Before testing the tool in the process of burning biscuits on the furnace, first test the temperature sensor reading using a comparator which is a sensor that has been installed on the tool. Testing was carried out for 1 hour between sensors temperature sensor 1 (T1) and temperature sensor 2 (T2) with the furnace default sensor. The result of the value of the comparison with the design tool has a reading of 31 ° C with 32 ° C, there is a difference of 1 ° C between the design tool and the comparator reading when used to measure room temperature.

The test results on the NodeMCU ESP8266-based thermocouple sensor using hot water can be seen in Table 1.

Table 1. MAX31855 sensor test results

Sensor 1 (°C)	Comparator (°C)	Difference	Error (%)	Accuracy (%)
31	32	1	3,12	96,88
44	43	-1	2,33	97,67
59	57	-2	3,51	96,49
68,5	66	-2,5	3,79	96,21
75,5	74	-1,5	2,03	97,97
Average		**-1,25**	**2,96**	**97,04**
Sensor 2 (°C)	**Comparator (°C)**	**Difference**	**Error (%)**	**Accuracy (%)**
31	32	1	3,13	96,87
53,25	52	-1,25	2,40	97,60
67,75	69	1,25	1,81	98,19
75,5	74	-1,5	2,03	97,97
79,75	78	-1,75	2,24	97,76
Average		**-0,45**	**2,32**	**97,68**

The test results in Table 1 obtained the temperature measurement results with the K-type thermocouple MAX31855 sensor with a comparison sensor in the form of an R-type thermocouple tested using hot water, from the measurement results it can be seen that this sensor has the largest difference of -2.5 ° C and the smallest difference of -1 ° C. The largest and smallest error rate in this test is 3.79% for the largest error, while the smallest error is 1.81%. The largest and smallest error rates in this test are 3.79% for the largest error, while the smallest error is 1.81%. Based on these results that the MAX31855 sensor with K-type thermocouple has a good level of accuracy and response, this sensor is suitable for temperature measurement with a long period of time because it has an accuracy of 97.68%.

D. Ceramic Firing Temperature Monitoring Test

Testing of the IoT-based ceramic firing temperature track monitoring tool was done in gas furnaces with a volume of 0.25 m^3 and is carried out in real time. This ceramic furnace uses two burners located at the back and front of the furnace as shown in Figure 6. The sensors were installed at the front and top of the furnace. This test was carried out with the aim of observing temperature changes that occur in the ceramic firing process. The temperature reading results then read on the LCD in real time every 1 second and recorded in Google Spreadsheet every 10 minutes.

The firing tests were carried out with a target temperature of 750 – 800 °C in 8 hours. At the start of firing, the burner used is the one located at the back of the furnace (Burner 1). After 4 hours or temperature reach of 350 – 400 °C, the front burner will be turned on to help increase furnace temperature. Firing is carried out to the biscuit firing stage at temperature of 750 – 800 °C. At 13.30 the burner 2 which is located in front of the furnace were turned on. At 15.10 the two burners were turned off when the temperature of sensor T1 had reached 801.00 °C and T2 had reached 780.50 °C.

Figure 7 shows the results of temperature monitoring which has been carried out with details of the implementation time reading. Firing starts at 09.02, using a burner located at the back of the furnace. Recordings are carried out every 10 minutes using two temperature sensors installed on the ceramic furnace. The first recording is 10 minutes after the furnace and module are turned on. There was difference in recording time between 10 minutes 0 seconds - 10 minutes 6 seconds due to the NodeMCU default settings so it affects the minute reading.

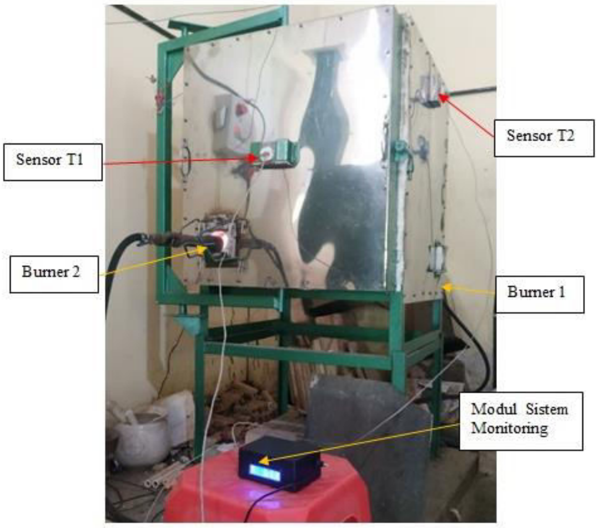

Figure 6. Temperature Monitoring Testing

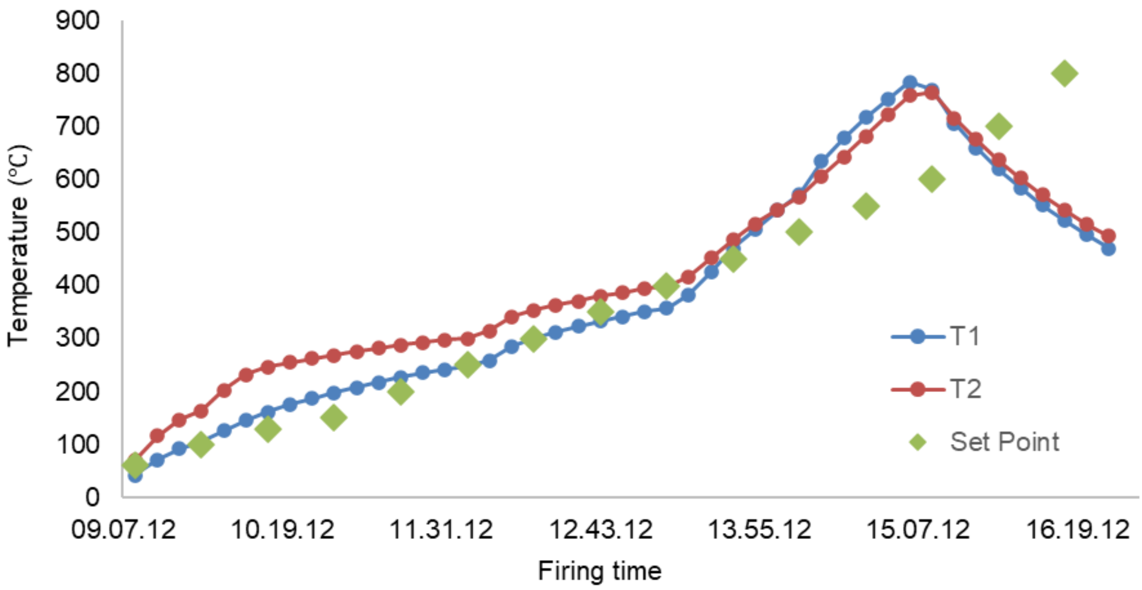

Figure 7. Recorded Temperature from the sensor T1 and T2 compare to the set point of ceramic firing processes

The graph shows the difference in temperature increase that occurs on T1 and T2 with the set point of ceramic firing processes. T2 reads a higher temperature than T1, this happens because the position of the burner that is first turned on is close to T2 which is located behind the furnace. The second burner is turned on at 13.30, where the position of the 2nd burner is located in front of the furnace close to T1. Burner 2 is turned on to speed up the firing process because the temperature has passed the dehydration stage, where the temperature of the dehydration stage occurs at a temperature of 200 - 400 °C. It can be seen that the temperature increase that occurs when reading T1 is starting to catch up and is higher than the temperature of T2. The temperature to be achieved in this firing is 750 - 800 °C, at the time the sensor has read a temperature above 750 °C the furnace operator carries out the soaking process (soaking period). The recorded T1 was 769.25 °C and T2 was 764.50 °C which had decreased due to the two burners being turned off. This means that the firing temperature of 750 – 800 °C, which should have taken 7.5 – 8 hours, was completed in 6 hours or 1.5 hours faster. This data can also be successfully recorded by the system and can be used as an indicator when the actual process differs from the set point.

CONCLUSION

An IoT-based ceramic firing temperature monitoring device for gas furnaces has been successfully developed. It can read and record firing temperature properly every 10 minutes in real time. The sensor can read temperature changes with the largest reading difference, namely -2.5 °C and the smallest difference, namely -1 °C, the average error from largest to smallest, for the largest error is 3.79%, while the smallest error is 1, 81%. In the future, it is hoped that this device can be tested in ceramic businesses, especially on a small and medium scale, as a low-cost technology option that can help reduce damage to ceramic products due to the firing process.

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