Design of temperature measuring instrument using NTC thermistor of Fe$_2$TiO$_5$ based on microcontroller ATmega 328

S S Munifah*, Wiendartun and A Aminudin

Physics Department, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Bandung West Java, Indonesia

*Corresponding author’s email address: sitisarahmunifah@student.upi.edu

Abstract. Thermistor is one of temperature sensor which works based on resistance changes and can be used as a temperature measuring instrument. In a previous study, an NTC thermistor of Fe$_2$TiO$_5$ was made in the form of raw pellet without doping, sintered at a temperature of 1200°C for 2 hours in oxygen. A thermistor constant value that obtained from the characterization process is 3821.65 K. This result showed that the thermistor has good quality because it has relatively large constant thermistor. Fe$_2$TiO$_5$ is one of semiconductors that used as basic material for main fabrication component of NTCs as temperature sensor. In this study, temperature measuring instrument using NTC thermistor of Fe$_2$TiO$_5$ sensor based on microcontroller ATMEGA 328. The NTC is assembled in parallel with a fixed resistor and then assembled on ICLM741 and microcontroller ATMEGA 328. The magnitude of the resistor varies at 1 MΩ, 2 MΩ, and 3 MΩ with each resistor having a tolerance value of 1%. From these variations we can get sensitivity value with the value of 0.00688 MΩ/°C; 0.0133 MΩ/°C, and 0.02195 MΩ/°C, respectively. As result, this temperature measuring instrument shows good sensitivity when assembled in parallel using 3 MΩ fixed resistor with a tolerance value of 1% and capable of measuring the temperature in the range 26°C – 103.2°C.

1. Introduction

Thermistor is one of the resistance types where its barrier value changes significantly when temperature change [1]. There are two types of thermistors, namely PTC and NTC. PTC is a type of thermistor which resistance value will increase when there is a temperature upgrading. While NTC is a type of thermistor which resistance value will decrease when there temperature upgrading. Currently there has been much development of NTC type thermistor, because this thermistor has more widely used for its linear sensitivity if it is compared with PTC. NTC thermistors have applications that can be used in various fields including, health, nuclear, electronic, and automotive [2].

Thermistor can be produced in the form of thin films, thick films and pellets [3]. The thermistor is made from a semiconductor material, a mixture of metal oxides, such as chromium, cobalt, iron, manganese, nickel, and uranium available in various shapes and sizes. Fe$_2$TiO$_5$ is one type of ceramic that its application can be used for NTC thermistors [4]. In a previous study, an NTC thermistor had been made before from Fe$_2$TiO$_5$, that was a raw pellet without doping sintered at a temperature of 1200°C for 2 hours in oxygen. The value of thermistor constants obtained from the characterization process in the previous study was in the range 4389-6149 K [4].

The digital thermometer is one of the technologies that can utilize the use of NTC as its temperature sensor. Digital thermometers are now being developed because they are widely used in various fields, such as in health, industry, and so on. Digital thermometers are more widely used than mercury...
thermometers because they are safer and easier to read. The rupture of mercury thermometers is very dangerous, because mercury is evaporated dangerously that can harm the brain, kidneys, heart, and lungs [5]. To anticipate the weakness of the thermometer, then a digital thermometer becomes an option. The digital thermometer has fast response and can measure the temperature with a smaller scale than the mercury thermometer. In addition, its use is also safer because it does not contain harmful substances such as mercury. This thermometer uses a temperature sensor as a device that detects temperature changes.

Microcontroller is an IC chip that serves to control the logic circuit. Microcontroller is widely used because it can facilitate human work in order to control various electronic devices. This tool reads the input, processes the program, and produces many outputs as needed [6]. One type of microcontroller is ATmega 328 microcontroller which is used on Arduino board. In Arduino there are 14 digital I/O pins, 6 analog input pins, power pins (5 V, 3.3 V, Ground, Vin, VREF / reference voltage), ICSP port, USB port, power socket, and reset button and ADC. In this research, a digital thermometer will be made using NTC Fe₂TiO₅. This prototype will be developed using Atmega328 microcontroller.

2. Methods

In this study, the materials being used consisted of NTC Fe₂TiO₅, ATmega328 microcontroller, PCB, 16x2 LCD, 10 KΩ potentiometer, capacitors of various sizes, resistors of various sizes, transformers, IC LM741, multiple connecting cables including male to male, male to female, and female to female, and black plastic box used to keep all the materials used.

The first step is to characterize NTC Fe₂TiO₅. Characterization is performed to obtain the value of thermistor constant (β) and R value at time T which corresponds to the following equation.

\[ R_T = R_0 e^{\beta/\Theta} \]  

Next, test the thermistor sensitivity using a resistor whose value is varied at 1 MΩ, 2 MΩ and 3 MΩ. From these results will be obtained three curves that the value of the slope of the curve line shows the sensitivity value. In addition, the purpose of composing NTC with resistors is to obtain a more linear curve. Then the research continued by testing the linearity of IC LM741 as operational amplifier used. Testing is done by comparing the input voltage value and output voltage generated by IC LM741. After that made the overall measuring system that can be shown by Figure 1 as follows.
The measuring system is made by composing the NTC in operational amplifier circuit, ATmega328 microcontroller and LCD as display. Microcontroller is programmed through computer on Arduino Uno software which aims to convert inputs into analog signals into digital signals. The digital signal is represented as the temperature displayed on the LCD directly. So that any changes in ambient temperature, then the display on the LCD will change. The research flow can be shown in Figure 2 below.

Then, testing the accuracy of the measuring system has been made by closer measuring system and reference thermometer on the heat source. Temperature changes that are read by both measuring devices are then compared to know the success of the tool that has been made. It can be shown in Figure 3 as follows.
3. Results and Discussion

Testing begins with characterization of NTC Fe$_2$TiO$_5$ which is done by giving heat treatment to NTC. The characterization results of NTC Fe$_2$TiO$_5$ can be shown in Figure 4 (a-b) as follows.

![Figure 3. The Process of Measuring Instrument Trial.](image)

**Figure 3.** The Process of Measuring Instrument Trial.

**Figure 4.** (a) R vs T Curve, (b) ln R vs 1/T Curve.

Figure 4(a) shows that the NTC Fe$_2$TiO$_5$ characteristic result is an exponential curve. This is consistent with equation 2.1 that the increase in temperature will be followed by an exponentially decreasing NTC resistance value. From the characteristic data that has been obtained, it can be made also a curve ln R vs 1/T shown by Figure 4.b which aims to obtain the constant value of NTC. From the curve is obtained by the value of the slope of the line of 3821.65 with the point - 9.59397 on the y-axis and the coefficient of determination of 0.99046. This means that the NTC Fe$_2$TiO$_5$ thermistor constant obtained from the characterization performed is 3821.65 K. The result of this characterization will be used in the program on microcontroller ATmega328.

To produce a good measuring instrument, linearity becomes necessary. Since the curve expressing the relationship between temperature change and NTC resistance is an exponential curve, the NTC needs
to be coupled parallel with the resistor so that the curve formed will have a linear tendency. In addition, a good measuring instrument should also have good sensitivity which means sensitive to changes that occur in the environment and can take action on those changes. Therefore, NTC characterization is arranged parallel with three variations of resistor value in order to get the best result. The resistor values used are 1 MΩ, 2 MΩ, 3 MΩ. The result of NTC characterized by parallel for each resistor value can be shown by Figure 5 as follows.

![Figure 5](image)

**Figure 5.** The characterization results of NTC which is arranged parallel with 3 variations of resistor value.

From Figure 5. We get three curves that express the relation between NTC and temperature. The slope of the line on the curve shows the value of NTC sensitivity in reading the temperature change. Of the three curves it can be seen that the NTC is coupled parallel with 3MΩ resistor has the largest slope of the line. The larger resistor values are paralleled with the NTC, the NTC will be more sensitive. When assembled in parallel with a resistor whose resistance value is 1 MΩ, NTC has a sensitivity value of 0.00259 MΩ / °C. Whereas if coupled parallel with resistor whose resistance value 2 MΩ, NTC has sensitivity value equal to 0.00913 MΩ / °C. Then when coupled parallel with resistors which resistance value is 3 MΩ, NTC has sensitivity value of 0.01548 MΩ / °C. Therefore a 3 M resistor is chosen in the circuit.

In addition to NTC characterization, IC LM741 testing is also performed as an operational amplifier that will be used on the measuring system. Characterization is performed to obtain the value reinforcement of IC LM741 (A) by determined the resistance value of resistor input (R1) and the value resistance of resistor input (R2) value arbitrarily which corresponds to the following equation.

\[ A = \frac{R_2}{R_1} + 1 \]  \hspace{1cm} (2)

The test is done in order to know the linearity of IC LM741 used. Test results can be shown on Table 1 as follows.
Table 1. Trial Data of IC LM741 Type UA741CP.

| No. | R1 (KΩ) | R2 (KΩ) | A_{\text{calculation}} | A_{\text{graph}} | Error |
|-----|---------|---------|------------------------|------------------|-------|
| 1.  | 5       | 10      | 3.00                   | 3.00             | 0     |
| 2.  | 10      | 50      | 6.00                   | 6.00             | 0     |
| 3.  | 5       | 50      | 11.0                   | 12.7             | 1.70  |
| 4.  | 50      | 100     | 3.00                   | 3.00             | 0     |
| 5.  | 10      | 100     | 11.0                   | 13.2             | 2.20  |

Table 1 shows that the IC LM741 used has good linearity. This is evidenced by the result of the reinforcement generated graph which states the ratio between the output voltage and the input voltage has a value almost equal to the obtained gain through the calculation. Therefore, IC LM741 is feasible to be used in measuring system.

Then after the measuring system is made, it is necessary to test the system of measuring instruments that have been made. Testing aims to determine the accuracy and temperature range that can be read by the system measuring instrument. Test results that have been done can be shown by Figure 6 as follows.

![Figure 6. NTC Thermometer vs Digital Thermometer Curve.](image)

From Figure 6 it can be seen that NTC Fe$_2$TiO$_5$ has a graph with the slope of the line for each experiment of 1.04916; 1.0442 and 1.02332 with a determination coefficient of each experiment of 0.99703; 0.99507 and 0.99655. From the graph, the slope of the line states the sensitivity of the digital thermometer. So that, this thermometer has a sensitivity of 1.0389 from the average of three times experiment. This means that every 1°C increase in the reference thermometer will be followed by a temperature increase of 1.0389 °C on an NTC digital thermometer. In addition, the accuracy error for each curve of the graph is 3.06%. This result is obtained from the average accuracy error of each datum.

4. Conclusions
A system of NTC Fe$_2$TiO$_5$ digital thermometer based on ATmega328 microcontroller has been successfully created. This temperature measuring system is equipped by the LCD as a display of temperature readings. The temperature range that can be read by this measuring system is 26°C – 103.2 °C with an accuracy error value of 3.06% against the reference thermometer.
5. References

[1] Zhang D, Shi M J, Chen L L, Ding S J 2013 Designing of Thermistor Digital Thermometer Based on Unbalanced Electric Bridge Trans Tech Publications, Switzerland, Key Engineering Materials 538 133-137

[2] Syarif D G 2007 Karakterisasi Keramik Termistor Fe2O3: 1mTi hasil sinter dan perlakuan panas. Jurnal Teknik Mesin Trisakti 9 1

[3] Putri R S, Ratnawulan, Syarif D G 2017 Pengaruh Penambahan ZrO2 Terhadap Karakteristik Termistor NTC Berbahan Dasar Fe2O3 Dari Mineral Yarosit Pilar of Physics 10 1

[4] Wiendartun, Risdiana, Fitriawati, R E Siregar 2016 The Effect of Sintering Atmosphere on Electrical Characteristics of FeTiO3 Pellet Ceramics Sintered at 1200°C for NTC Thermistor Journal of Physics: Conference Series 739

[5] Nusi D T 2013 Perbandingan Suhu Tubuh Berdasarkan Pengukuran Menggunakan Termometer Air Raksa dan Termometer Digital pada Penderita Deman di Rumah Sakit Umum Kondou Manado Jurnal e-Biomedik (eBM) 1 1 190-196

[6] Prima E.C 2016 Automatic Water Tank Filling System Controlled using Arduino™ based Sensor for Home Application Engineering Physics International Conference, EPIC 2016 Procedia Engineering 170 373 – 377