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Development of Temperature Measurement and Monitoring System on Machine with Thermal Camera AMG8833 based Internet of Things (IoT)

Heri Firmansyah, Widyaningrum Indrasari, Ridho Achmadi
Department of Electronic Engineering, Faculty of Engineering,
Department of Physics, Faculty of Mathematics and Sciences,
Universitas Negeri Jakarta
Jakarta, Indonesia
heri.firmansyah@unj.ac.id

***Abstract*— Engine temperature monitoring needs to be done to prevent engine overheating. In this study, an engine temperature monitoring system was designed using an AMG8833 thermal camera sensor. This system is equipped with an AMG8833 thermal camera sensor to read temperature values, a Raspberry Pi 3B+ as a controller, a buzzer as an indicator if the temperature is more than 60°C, and a monitor screen as a display. In this study, sensor characterization has been done, so that the optimal measurement distance range of the sensor in measuring engine temperature is 1 cm to 7 cm and a sensor accuracy of 99.88%. The sensor can work well in a temperature range of 30°C to 70°C. In addition, the sensor has a resolution of 1°C. Engine temperature monitoring is conduct through a website-based system. The monitoring system has successfully in detecting the temperature of motorbike engines, car engines, and irons. In addition, the system has succeeded in monitoring the temperature for 24 hours. Based on this, it can be concluded that the system can work properly in monitoring the temperature of engines with IoT-based.**

***Index Terms*— AMG8833 Sensor, Engine Temperature, Monitoring.**

I. INTRODUCTION

The manufacturing industry around the world is currently undergoing a significant transformation known as the Industrial Revolution 4.0 (IR 4.0). In industrial machines, electrical energy is converted into mechanical energy. When the machine is working, the temperature of the machine usually increases [1]. Heat is a form of energy that flows and moves due to differences in temperature [2]. The condition of a machine temperature that exceeds its normal limit is called overheating. Therefore, to avoid overheating in the machine, maintenance is needed to support the production process [3]. Maintenance on the machine consists of several types of actions, i.e., corrective maintenance, preventive maintenance, and predictive maintenance. Corrective maintenance only take place when the machine stops working. Preventive maintenance is a maintenance technique that conducted periodically with a planned schedule to anticipate machine failure. Predictive maintenance uses predictive tools to determine when maintenance action is needed [4].

In predictive maintenance, there is a Conditions-based Monitoring (CbM) method. CbM is defined as a predictive maintenance strategy that continuously monitors machine conditions using several types of sensors and uses data taken from sensors to monitor machines in real time. The machine condition maintenance process must be conducted so that the machine has reliable performance or a reasonable condition to carry out the production process. If the machine does not get maintenance, usually the machine will be damaged if used continuously. As a result, production is disrupted, and the production process cannot be conducted. So, it is necessary to monitor the machine regularly.

Machine monitoring needs to be done so that nothing bad happens to the machine. Machine monitoring is used to prevent overheating conditions. A fire at machine can occur if the condition is already overheating but is still being supplied with electricity. This can cause the electrical system of the machine to melt or burn. By monitoring temperature changes, physical changes that occur in the machine can be identified. This is what makes temperature one of the indicators in knowing the changes in the condition of a machine. In monitoring the temperature on the machine, a temperature measuring instrument needs to be used. There are many temperature measuring instruments sold on the market. According to Momentous, there are several examples of temperature measuring instruments on industrial machines, thermometers, thermocouples, temperature gauges, and thermo guns. However, the weakness of these measuring instruments must be operated by experts so that the condition of the machine can be identified when overheating. If the machine operates 24 hours a week, then experts must always monitor it. Therefore, to increase efficiency, a system is needed that can monitor the machine temperature. The system must be usable at any time and can be monitored remotely. In monitoring the temperature conditions on the machine, the Internet of Things (IoT) is a technology that can assist remote and at any time monitoring.

IoT is a concept that aims to expand the benefits of continuously connected internet connectivity. IoT can connect machines, equipment, and other physical objects with network sensors and actuators to obtain data and manage their own performance. Thus, allowing machines to collaborate and even act on current information obtained independently. With IoT, devices connected to the internet can collect, receive, and communicate with each other and be integrated in their use. The use of IoT is very much needed in industry, especially in monitoring temperature conditions in machines. This can increase efficiency in monitoring machine temperature measurements.

II. Temperature Measurement with Thermal Camera

The IR Thermal Camera is a non-contact sensor device that can detect heat or infrared energy and convert it into electrical energy or electronic signals, which can then be processed to produce thermal images. In addition to producing thermal images, these electronic signals can also be used to calculate or measure temperature. AMG8833 is one type of IR thermal camera sensor that has an 8×8-pixel thermal sensor array made by Panasonic. AMG8833 only supports I2C and has a configurable interrupt pin that can be activated when each pixel goes above or below the desired threshold. The AMG8833 Thermal Camera when connected to a microcontroller or Raspberry Pi will display an array of 64 individual infrared temperature reading pixels per pixel. AMG8833 has a wide field or angle of view for infrared readings, namely a 60 ° wide field of view on both the horizontal and vertical sides. This AMG8833 is a simple IR thermal camera sensor so that it can be easily integrated, and its data output can be accessed via I2C communication with the address 0x69. The AMG8833 can measure temperatures ranging from 0°C to 80°C with an accuracy of ±2.5°C. This sensor is also capable of detecting humans up to 7 meters with a maximum frame rate of 10 Hz. How the AMG8833 thermal camera sensor works is like an infrared pyrometer or infrared thermometer that measures the temperature of an object non-contact by detecting infrared energy or thermal energy emitted by the object. The following is the working principle of the AMG8833 thermal camera sensor:

1) Infrared Technology: The AMG8833 sensor uses infrared technology to detect the temperature of an object. Infrared is electromagnetic radiation that is invisible to the human eye but can be detected by a thermal camera sensor.

2) Thermopile Array: The AMG8833 has a 64-pixel (8x8) thermopile array that can measure the temperature of a radiation object. A thermopile is a sensor that produces voltage based on the temperature difference between two measurement points.

3) Data Processing: The AMG8833 sensor processes data from the thermopile array to produce a thermal image that shows the temperature distribution of the object. Each pixel in the thermopile array represents the temperature of the measured area.

The following Fig.1 is a picture AMG8833 thermal camera sensor and Fig.2 internal circuit of the AMG8833.

Fig. 1. AMG8833 thermal camera sensor

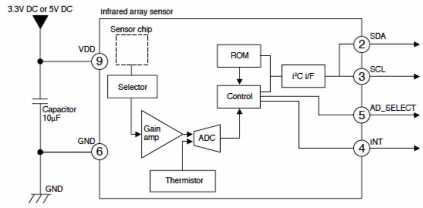

Fig. 2. Internal circuit of the AMG8833

A. The Temperature Sensor Working Principle

The heat exchange between the IR sensor and the object is illustrated in Fig. 3. If the optical coupling between the object and the sensor is not perfect, the sensor can receive unwanted thermal flux from an external object that has a temperature of T_X. Although the object is not in the field of view of the IR sensor. The measurement object has a temperature of T_B and a surface emissivity of ε_B, so it emits a flux ΦB towards the IR sensor proportional to the emissivity. However, because $\varepsilon_B < 1$, the object is reflective, so some of the stray flux ΦX equal to $\Phi_X(1-\varepsilon_B)$ will be reflected by the object towards the IR sensor. The dummy IR flux will cause errors in the measurement because it is added to the used flux. Therefore, the lack of IR optical coupling between the object and the non-contact sensor is a potential source of error [5].

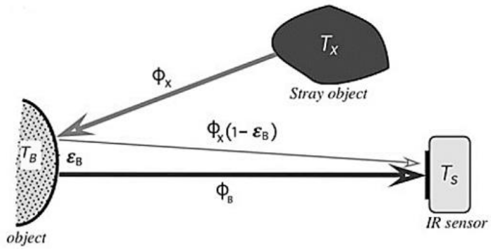

Fig. 3. Radiation coupling between object and IR non-contact sensor

In measuring engine temperature, it can be detected by the presence of infrared rays produced by the engine. To detect the presence of these rays, many measuring instruments can be used. One measuring instrument that can monitor engine temperature using infrared radiation is a thermal camera. Thermal cameras are usually used to monitor industrial equipment, especially industrial machines [6].

This camera is different from ordinary cameras that utilize light reflection to objects such as the human eye. However, the image obtained from the thermal camera is a representation of the infrared radiation emitted by the target object. Thermal cameras can monitor an object without a visible light source, thermal cameras have several advantages, including being able to measure the temperature of dangerous objects without having to touch (non-contact) and being able to measure for a long time without causing radiation effects. Based on these advantages, thermal cameras are usually used to measure objects whose temperatures are estimated to be hot. The use of thermal cameras can monitor the temperature conditions of the engine captured by the camera [7]. So that the condition of temperature increase beyond normal limits can be prevented immediately. The use of thermal cameras in monitoring engine conditions using thermal images is more effective than conventional monitoring methods [8]. Therefore, thermal cameras are needed in monitoring engine temperatures.

B. Experimental method

The research method used in this study is experiment and development. This research method is designing a thermal camera to monitor engine temperature. The output data is used to analyze the overheating conditions in the engine. The development of an IoT-based engine temperature monitoring system has been conducted. This system is used to monitor engine temperature as a form of predictive engine maintenance based on the CbM method. The system monitors engine temperature conditions by displaying them as temperature values. This system uses IoT technology that is integrated through a website. So that the temperature value data generated by the system is stored in a database, then can be accessed via the website as a data recording server. The use of IoT aims for remote monitoring at any time. The sensor in this system uses the AMG8833 thermal camera sensor. This system uses Raspberry Pi as its controller. This is because Raspberry Pi has the same capabilities as computers in general. It is hoped that the development of this system can increase the efficiency of monitoring engine temperature conditions.

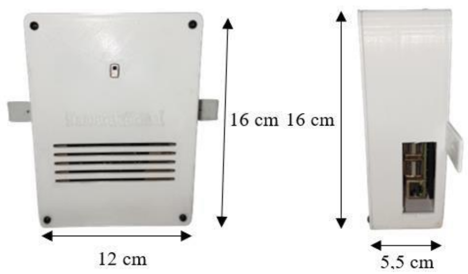

Fig. 4. The design of a temperature monitoring system using an IoT-based

The Fig. 4. shows the appearance or design of a temperature monitoring system on a machine using an IoT-based thermal camera. On the front of the system there is an AMG8833 thermal camera sensor that functions to detect or capture thermal radiation or infrared radiation on an object, especially a machine. On the front there is also a ventilation hole that functions for air circulation. On the side there is a hole to insert a USB. On the top there is a buzzer that functions to provide a sound indicator when the machine temperature is more than 60°C. On the bottom there is a hole to insert the Power Supply. The Raspberry Pi 3B+ components are placed inside the system, so they are not visible to the user.

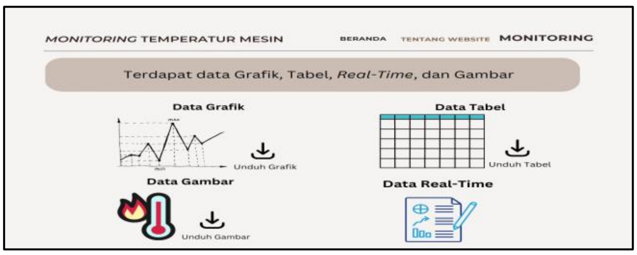

Fig. 5. The website design in the "Monitoring" menu

Fig. 5. shows the appearance or design of the IoT-based engine temperature monitoring system. On the engine temperature monitoring website, there are 3 main menus, namely Home, About Website, and Monitoring. The "Home" menu contains an explanation of engine temperature monitoring in general. The "About Website" menu contains an explanation of the website and engine temperature measurement prototype. While the "Monitoring" menu contains temperature data in the form of graphs, tables, real-time, and images.

C. Experimental results and considerations

The results of the research conducted are the characterization of the AMG8833 thermal camera sensor, hardware design, website design, system integration with the website, and testing of the entire system. The initial stage in characterizing is to determine the optimal distance from the AMG8833 thermal camera sensor. In determining the optimal distance of the sensor, the heat source used is a stirrer at a temperature of 50.80°C, the measurement results of the AMG8833 thermal camera sensor against the stirrer heat source are shown in Table 1.

TABLE I. Optimal distance of AMG8833 thermal camera sensor to stirrer

Measurement	Temperature (°C)						
	1 cm	2 cm	3 cm	4 cm	5 cm	6 cm	7 cm
1	48,88	49,13	49,13	48,75	48,88	48,51	48,51
2	48,81	48,56	49,13	48,88	48,53	48,51	48,51
3	48,25	49,33	49,13	48,88	48,88	48,50	48,50
4	49,50	48,81	48,97	48,75	48,69	48,50	48,50
5	48,75	48,94	49,13	48,75	48,69	48,44	48,38
6	48,75	48,69	49,13	48,75	48,88	48,44	48,38
7	49,50	48,38	48,97	48,55	48,53	48,31	48,38
8	49,50	49,50	48,97	48,53	48,53	48,38	48,31
9	48,69	49,33	48,97	48,73	48,25	48,38	48,19
10	48,69	49,13	48,87	48,73	48,25	48,31	48,31
11	48,69	49,50	48,87	48,56	48,13	48,44	48,31
12	49,50	49,33	48,87	48,56	48,13	48,31	48,25
13	49,50	48,81	48,97	48,56	48,13	48,31	48,25
14	48,75	48,69	48,97	48,50	48,25	48,19	48,25
15	48,25	48,69	48,97	48,50	48,25	48,19	48,19
Average (°C)	48,93	48,99	49,00	48,67	48,47	48,38	48,35
Error (%)	3,67	3,57	3,54	4,20	4,59	4,76	4,83
Std. Dev (°C)	0,45	0,36	0,10	0,13	0,29	0,11	0,11

Based on Table I, the optimal measurement distance using the AMG8833 thermal camera sensor for measuring the heat source in the stirrer is 1 cm to 7 cm. The selection of this distance range is based on the results of its low relative error compared to other distance ranges. In the distance range of 1 cm to 7 cm, there was also no significant difference. Therefore, this distance range is the optimal choice to achieve effective measurements. In the measurement range of 1 cm to 7 cm, a minimum relative error of 3.54% and a maximum relative error of 4.83% were obtained. The next step in characterizing the AMG8833 thermal camera sensor is to directly compare the values read on the sensor with the values read on the industrial thermogun. For this stage, measurements are taken at the heat source in the stirrer, because the stirrer has a knob (heat level regulator). Measurements are taken at a distance of 3 cm. At this distance, the AMG8833 thermal camera sensor has been proven to provide accurate and consistent measurement results, as obtained from the previous analysis. Meanwhile, the measurement distance of the industrial thermogun with the heat source adjusts the sensor distance, which is 3 cm. The industrial thermogun does not have an optimal distance range specification. Thus, it is assumed that temperature measurements at any distance in the industrial thermogun have good accuracy and consistency. The results of the temperature characterization of the AMG8833 thermal camera sensor are shown in Fig. 6.

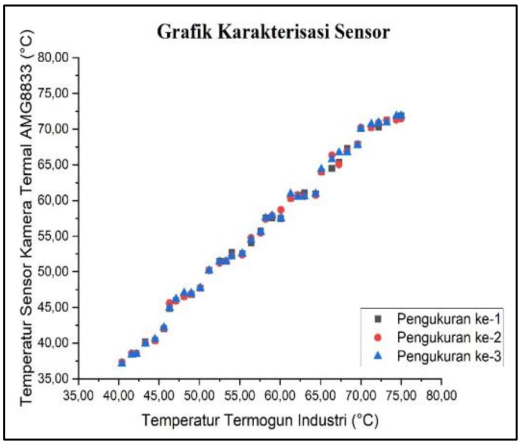

Fig. 6. AMG8833 thermal camera sensor temperature characterization results

As Fig.6. shows a direct comparison graph between the temperature values read on the AMG8833 thermal camera sensor and the temperature values read on the industrial thermogun. Sensor temperature measurements were conducted 3 times at an industrial thermogun temperature range of 40°C to 75°C, with an increase in the industrial thermogun temperature every 1°C. This temperature range was chosen to cover a variety of temperature conditions that the AMG8833 thermal camera sensor might be able to reach based on the sensor datasheet. The measurement process started from an industrial thermogun temperature of 40°C and was re-measured when the industrial thermogun temperature had reached 75°C. Temperature data collection in each measurement was carried out with an interval of 2 seconds.

Thermal camera system testing was conducted in measuring temperature after the sensor characterization process and hardware design. This test was conducted at an optimal measurement distance range, which is 3 cm with an object in the form of a pan. Table II. is the result of temperature measurements from the AMG8833 thermal camera sensor. Based on the test results of the AMG8833 thermal camera system in the range of 32.50˚C to 65.70˚C have an average relative measurement error value of 0.12% which is relatively low and an accuracy of 99.88% which indicates good accuracy. Meanwhile, in the range of 71.30˚C to 74.90˚C, it can be seen that the sensor experienced an increase in the average relative measurement error to 1.90% and a decrease in accuracy to 98.10%. This indicates that the sensor is starting to experience limitations or weaknesses in measuring temperature in that range. The temperature range above 70.00˚C is not an effective working area for the AMG8833 thermal camera sensor, because the measurement accuracy decreases and the relative error value increases. Based on these findings, it can be concluded that the AMG8833 thermal camera sensor has been successfully characterized and can be relied on for use as a temperature detection component on machines operating in the range of 30.00˚C to 70.00˚C. Then based on the test, the integration of the system and casing on the thermal camera has been successfully carried out and the system is running properly and can be relied on.

TABLE II. Thermal camera system test data

Temperature (°C)		***Error*** **(%)**
Industrial Thermogun	**Thermal Camera AMG8833**	
32,50	32,48	0,06
37,70	37,68	0,05
45,70	45,61	0,20
50,90	50,81	0,18
57,70	57,64	0,10
65,70	65,61	0,14
71,30	70,33	1,36
72,30	71,06	1,72
74,90	72,93	2,63

The linear regression equation will be the calibration equation of the AMG8833 thermal camera sensor as follows.

$$y = 0.9339x + 5.4558$$

Based on Equation, the regression coefficient representing the slope of the linear regression line (a) shows how much the value of the dependent variable (y) changes for every one unit change in the independent variable (x). Meanwhile, the regression coefficient c represents the point where the regression line intersects the y-axis (y-intercept) and shows the temperature value at x = 0. Then, it can also be seen that the value of x is the temperature value read by the AMG8833 thermal camera sensor. While the value of y is the temperature value after calibration or the actual temperature measured by the sensor in °C units. By using the linear regression method and data from these components, the calibration equation used to predict the temperature value on the AMG8833 thermal camera sensor can be calculated. The calibration equation will help in interpreting and using the results of sensor measurements accurately and reliably in their use.

III. CONCLUSION

In this paper, we developed the design of the IoT temperature thermal camera system. The system is equipped with an AMG8833 thermal camera sensor to read temperature values, a Raspberry Pi 3B+ as a controller, a buzzer as an indicator if the temperature is more than 60°C, and a monitor screen as a display. The AMG8833 thermal camera sensor has a distance of 1.5 cm which is a distance with good precision. The sensor has a working range of 30°C to 70°C 1˚C. Based on work testing, the sensor has an average relative measurement error value of 0.12% which is low, indicating good accuracy. We are creating a website for an engine temperature monitoring system. On the website there are 3 main menus, Home, About Website, and Monitoring. The features that can be displayed on the website consist of engine temperature graphs, engine temperature tables, real-time engine temperature monitoring, and thermal image monitoring. The system integration process with the website is conducted by connecting the Raspberry Pi to the database so that the data read on the sensor can be stored and displayed on the website.

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