Thermal Image Processing Using Artificial Neural Network for Boiler TV-Furnace (Thermal CCTV) Position Control System

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Abstract. Improving production system quality, especially in the efficiency of coal combustion, is a must to optimize the electric energy production of a power plant. To maintain customer trust, towards an international standard distribution process, it needs innovation in combustion monitoring. Overheating conditions frequently occur and could break the camera due to limited information on combustion temperatures received by the user. From these problems, this study aims to design a classification system for monitoring the combustion process in the boiler or furnace. Combustion area captured by the Adafruit AMG-8833 IR camera and continued with the extraction and segmentation of thermography analysis and neural network (NN). This study utilizes the features of temperature conversion in each image segment in the form of HSV (Hue, Saturation, Value). Hue parameters (H) and value (V) parameters are used in the classification process for its large degree of red to green differences with a significant range at each temperature. Those parameters are the input of the Artificial Neural Network along with the average & overheating temperature as the classification target. The average error of this system is 0.08559% for the image classification with training data of 64x45 inputs, 16 neurons, and the best performance at 10th repetition.

Keywords: Boiler Furnace, overheating, IR-Thermal camera Adafruit amg-8833, thermography analysis

1. Introduction
Reviewing system reliability, it is closely related to the instrumentation control systems to support system sustainability. It has been widely known that a generator instrumentation system always has the possibility of a problem with its measuring equipment, either on the sensors or other equipment. Especially in the combustion process which must be monitored optimally. Improvement of the production quality especially in the efficiency of coal combustion which has been constrained so far, by many frequent overheating conditions. Monitoring of the current combustion process was no longer compatible if still use a conventional camera furthermore, it is causing damage to the “furnacea” itself
due to the delay in temperature information integrated with the user / operator, On this research is expected to carry out a classification system design as well as monitoring the combustion process boiler combustion or furnace using thermography analysis.

2. Methodology
This study is to provide innovation using the implementation of Visual Process Technology and artificial intelligence. Visual Process technology with Image Processing is uses thermography according to temperature distribution of each point in the boiler furnace. So that the relationship between pixels for conversion process and color mapping of each image. Then it will be processed using feature extraction to produce data form ] histogram with 3 parameters, namely HSV (Hue, Saturation, and Value) and from these 3 parameters taken a significant difference value that will be used as input in classifying using the Neural Network.

2.1. IR- Thermography
Also known as thermal imaging actually visual displays of the amount of infrared energy emitted, transmitted, and reflected by an object. Because there are multiple sources of the infrared energy, it is difficult to get an accurate temperature of an object using this method. A thermal imaging camera is capable of performing algorithms to interpret that data and build an image. Although the image shows the viewer an approximation of the temperature at which the object is operating, the camera is actually using multiple sources of data based on the areas surrounding the object to determine that value rather than detecting the actual temperature. In this study AMG IR-8833 Thermal camera is used to sensing the role condition, AMG IR-8833 is classified as an infrared-based camera with an array of 8x8 grid segments (matrix) or with a circumference of about 64 points. Infrared temperature reading,

2.2. RGB
RGB color space is the main three colors (the three primary colors) which consists of three color channels, red, green, and blue and its all can be combined in various proportions to obtain any color in the visible spectrum. Each color channel is limited to a value of 0 - 255 or in other words there can be
256 levels. If the color channel is combined then there are $256 \times 256 \times 256$ or $16,777,216$ RGB color combinations produced.

2.3. HSV

HSV model was created in 1978 by Alvy Ray Smith. It is a nonlinear transformation of the RGB color space. HSV (Hue, Saturation and Value) defines a type of color space. It is also similar to the modern RGB. HSV color space has three components: hue, saturation and value. ‘Value’ is sometimes substituted with ‘brightness’ and then it is known as HSB. The HSV model was HSV is also known as the hex-cone color model. In HSV, hue represents color. In this model, hue is an angle from 0 degrees to 360 degrees. Saturation indicates the range of grey in the color space. It ranges from 0 to 100%. Sometimes the value is calculated from 0 to 1. When the value is ‘0,’ the color is grey and when the value is ‘1,’ the color is a primary color. A faded color is due to a lower saturation level, which means the color contains more grey. Value is the brightness of the color and varies with color saturation. It ranges from 0 to 100%. When the value is ‘0’ the color space will be totally black. With the increase in the value, the color space brightness up and shows various colors to simplify the explanation figure 1 is HSV model.

![Image](image.png)

**Figure 3. HSV Color model**

2.4. Neural Network

Neural networks (NN) are parallel information processing systems consisting of a number of simple neurons (also called nodes or units), which are organized in layers and which are connected by links. The artificial neural networks imitate the highly interconnected structures of the brain and the nervous system of animals and humans whereby the neurons correspond to the cell bodies and the links are equivalent to the axons in biology. An example of a multilayer feedforward neural network for this study is shown in figure 2.

![Image](image.png)

**Figure 4. NN Perceptron Scheme.**
2.5. Data Training

From the results of the conversion in Figure 5. The control system design above obtained 3 input vectors in the form of H, S, and V values which will then be continued processing to obtain 1 output value as a motor indicator, an example is seen in the following table:

| Table 1. Example of Back Propagation Preparation |
|---|---|---|---|
| Epoch No | X1 | X2 | X3 | Yd |
| 1 | 1 | 0 | 0 | 1 | 0 |
| 2 | 0 | 1 | 1 | 0 |
| 3 | 1 | 0 | 1 | 1 |
| 4 | 1 | 1 | 1 | 1 |

*Explanation:* 
X1 = Value H; X2 = Value S; X3 = Value V with the value as in the table, an example of output is Desired Output (Yd), where Desired output itself is the result of the operation of the algorithm which will be used as a benchmark for motor activation output. With reference to 3 motor conditions for each particular Value such as 0 subject to insert, 1 subject to retract and 0 to 0.8 subject to standby scheme can be seen in Figure 2.3 above.

3. Testing and Data Analysis

In this Study begins with capturing object by AMG THERMAL CAMERA IR 8833 obtaining HSV values as input parameters in NN. Based on the conversion data obtained, the value of Hue and Value with a high value difference so that each image taken by the sensor will obtain data with a matrix arrangement of 8x8 or with a circumference of about 64. For more accurate and efficient training, reshape the 8x8 matrix data to a 1x64 matrix and it will as an neural network input parameters after get the all HSV value. To get HSV values based on RGB, there are several ways (Kadir and Susanto, 2013). The simplest way according to Acharya and Ray is as follows:

\[ H = \tan \left( \frac{3(G - B)}{(R - G) - (R - B)} \right) \] (1)
\[ S = 1 - \frac{\min(R,G,B)}{V} \]  
(2)

\[ V = \frac{R+G+B}{3} \]  
(3)

However, this method makes hue undefined if \( S \) is zero. The second method according to Acharya and Ray (Kadir and Susanto, 2013) is found in the formulas used as follows:

\[ r = \frac{R}{R+G+B}, \quad g = \frac{G}{R+G+B}, \quad b = \frac{B}{R+G+B} \]  
(4)

\[ V = \max(r, g, b) \]  
(5)

\[ S = \begin{cases} 
0, & \text{jika } V = 0 \\
1 - \frac{\min(r,g,b)}{V}, & \text{jika } V > 0 
\end{cases} \]  
(6)

\[ H = \begin{cases} 
0, & \text{jika } S = 0 \\
\frac{60 (g-b)}{S V}, & \text{jika } V = r \\
60 \left[ 2 + \frac{b-r}{S V} \right], & \text{jika } V = g \\
60 \left[ 4 + \frac{r-b}{S V} \right], & \text{jika } V = b 
\end{cases} \]  
(7)

\[ H = H + 360, \quad \text{jika } H > 0 \]  
(8)

Formula description:
R = red value has not been normalized
r = normalized red value
G = green value has not been normalized
G = normalized green value
B = blue value has not been normalized
b = normalized blue value

3.1. RGB Value from the camera

| row/ column | R value in RGB data 888 range 0-255 |
|-------------|-------------------------------------|
| row column  | 1 2 3 4 5 6 7 8                    |
| 1           | 0 0 0 0 0 0 0 0                     |
| 2           | 0 0 0 0 0 16 8 255                 |
| 3           | 0 0 0 0 0 230 0 0                   |
| 4           | 0 0 0 0 0 0 0 0                     |
| 5           | 0 0 0 0 0 0 0 0                     |
| 6           | 0 0 0 0 0 0 0 0                     |
| 7           | 0 0 0 0 0 0 0 0                     |
| 8           | 0 0 0 0 0 0 0 0                     |
Table 3. Conversion value of temperature data to decimal (color pallet) 16 bits in 8x8 G matrix

| row/column | G value in RGB data 888 range 0-255 |
|------------|-------------------------------------|
|            | 1 2 3 4 5 6 7 8                     |
| 1          | 28 28 49 77 121 174 182 190        |
| 2          | 20 20 28 69 178 202 198 0          |
| 3          | 12 12 28 49 174 174 186 186        |
| 4          | 4 4 12 28 49 109 109 109           |
| 5          | 4 4 12 28 28 49 61 69              |
| 6          | 12 4 12 20 28 28 40 49             |
| 7          | 20 12 12 20 20 20 20 40            |
| 8          | 69 40 20 28 28 28 28 49            |

Table 4. Conversion value of temperature data to decimal (color pallet) 16 bits in 8x8 B matrix

| row/column | B value in RGB data 888 range 0-255 |
|------------|-------------------------------------|
|            | 1 2 3 4 5 6 7 8                     |
| 1          | 148 148 148 156 165 156 107 41     |
| 2          | 148 148 148 156 123 0 0 0          |
| 3          | 148 148 148 148 148 0 74 74        |
| 4          | 140 148 148 148 148 156 156 156    |
| 5          | 140 140 148 148 148 148 156 156    |
| 6          | 148 140 148 148 148 148 148 148    |
| 7          | 148 148 148 148 148 148 148 148    |
| 8          | 156 148 148 148 148 148 148 148    |

3.2. RGB to HSV Result

Table 5. Conversion value of temperature data to decimal (color pallet) 16 bits in 8x8 H matrix

| row/column | H value in RGB 888 conversion data range 0-1 |
|------------|----------------------------------------------|
|            | 1 2 3 4 5 6 7 8                             |
| 1          | 0,6351 0,6351 0,6115 0,5844 0,5444 0,4828 0,4313 0,3693 |
| 2          | 0,6441 0,6441 0,6351 0,5929 0,4485 0,3201 0,3266 0 |
| 3          | 0,6532 0,6532 0,6351 0,6115 0,4751 0,1261 0,3996 0,3996 |
| 4          | 0,6619 0,6532 0,6532 0,6351 0,6115 0,5502 0,5502 0,5502 |
| 5          | 0,6619 0,6619 0,6532 0,6351 0,6351 0,6115 0,6015 0,5929 |
| 6          | 0,6532 0,6619 0,6532 0,6441 0,6351 0,6351 0,6216 0,6115 |
| 7          | 0,6441 0,6532 0,6532 0,6441 0,6441 0,6441 0,6216 0,6216 |
| 8          | 0,5929 0,6216 0,6441 0,6351 0,6441 0,6351 0,6351 0,6115 |
Table 6. Conversion value of temperature data to decimal (color pallet) 16 bits in 8x8 S matrix

| row/column | S value in RGB 888 conversion data range 0-1 |
|------------|---------------------------------------------|
|            | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
| 1          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 2          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 3          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 4          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 5          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 6          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 7          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |
| 8          | 1   | 1   | 1   | 1   | 1   | 1   | 1   | 1   |

Table 7. Conversion value of temperature data to decimal (color pallet) 16 bits in 8x8 V matrix

| row/column | V value in RGB 888 conversion data range 0-1 |
|------------|---------------------------------------------|
|            | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
| 1          | 0.5804 | 0.5804 | 0.5804 | 0.6118 | 0.6471 | 0.6824 | 0.7137 | 0.7451 |
| 2          | 0.5804 | 0.5804 | 0.5804 | 0.6118 | 0.698 | 0.7922 | 0.7765 | 1 |
| 3          | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.6824 | 0.902 | 0.7294 | 0.7294 |
| 4          | 0.549 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.6118 | 0.6118 | 0.6118 |
| 5          | 0.549 | 0.549 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.6118 |
| 6          | 0.5804 | 0.549 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 |
| 7          | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 |
| 8          | 0.6118 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 | 0.5804 |

In this study, the Hue and Value params use as input for neurons for training because it has a high difference in the value of each cell and the reshape of the 8x8 matrix data becomes a 1x64 matrix by transposing the matrix using the following formula:

\[ B = \text{reshape}(A',[],1); \]

**Transpose Matriks**

- \((A + B)^T = A^T + B^T\)
- \((A^T)^T = A\)
- \(\lambda(A^T) = (\lambda A^T)\), if \(\lambda\) scale
- \((AB)^T = B^T A^T\)

From the formula above 1x64 matrix is reshaped as the following table:
Table 8. reshaped data training

| No. Rows | Value          | No. Rows | Value          | No. Rows | Value          | No. Rows | Value          |
|----------|----------------|----------|----------------|----------|----------------|----------|----------------|
| 1        | 0.549019607    | 17       | 0.549019607    | 33       | 0.549019607    | 49       | 0.549019607    |
|          | 843137         |          | 843137         |          | 843137         |          | 843137         |
| 2        | 0.549019607    | 18       | 0.549019607    | 34       | 0.549019607    | 50       | 0.549019607    |
|          | 843137         |          | 843137         |          | 843137         |          | 843137         |
| 3        | 0.549019607    | 19       | 0.549019607    | 35       | 0.549019607    | 51       | 0.549019607    |
|          | 843137         |          | 843137         |          | 843137         |          | 843137         |
| 4        | 0.549019607    | 20       | 0.549019607    | 36       | 0.549019607    | 52       | 0.580392156    |
|          | 843137         |          | 843137         |          | 843137         |          | 862745         |
| 5        | 0.549019607    | 21       | 0.549019607    | 37       | 0.549019607    | 53       | 0.549019607    |
|          | 843137         |          | 843137         |          | 843137         |          | 843137         |
| 6        | 0.549019607    | 22       | 0.580392156    | 38       | 0.549019607    | 54       | 0.580392156    |
|          | 843137         |          | 862745         |          | 843137         |          | 862745         |
| 7        | 0.549019607    | 23       | 0.580392156    | 39       | 0.580392156    | 55       | 0.580392156    |
|          | 843137         |          | 862745         |          | 862745         |          | 862745         |
| 8        | 0.549019607    | 24       | 0.549019607    | 40       | 0.580392156    | 56       | 0.580392156    |
|          | 843137         |          | 862745         |          | 862745         |          | 862745         |
| 9        | 0.549019607    | 25       | 0.549019607    | 41       | 0.549019607    | 57       | 0.549019607    |
|          | 843137         |          | 843137         |          | 843137         |          | 843137         |
| 10       | 0.549019607    | 26       | 0.549019607    | 42       | 0.549019607    | 58       | 0.580392156    |
|          | 843137         |          | 843137         |          | 843137         |          | 862745         |
| 11       | 0.549019607    | 27       | 0.549019607    | 43       | 0.549019607    | 59       | 0.580392156    |
|          | 843137         |          | 843137         |          | 843137         |          | 862745         |
| 12       | 0.549019607    | 28       | 0.549019607    | 44       | 0.580392156    | 60       | 0.580392156    |
|          | 843137         |          | 862745         |          | 862745         |          | 862745         |
| 13       | 0.549019607    | 29       | 0.549019607    | 45       | 0.549019607    | 61       | 0.580392156    |
|          | 843137         |          | 843137         |          | 843137         |          | 862745         |
| 14       | 0.549019607    | 30       | 0.549019607    | 46       | 0.549019607    | 62       | 0.580392156    |
|          | 843137         |          | 843137         |          | 843137         |          | 862745         |
| 15       | 0.549019607    | 31       | 0.580392156    | 47       | 0.580392156    | 63       | 0.580392156    |
|          | 843137         |          | 862745         |          | 862745         |          | 862745         |

3.3. Neural Network Input (Training)

By obtaining the conversion of values above, then it will continue to get the value of the input system with the results of training data. In this study use 37 input imaging data for training with 16 neurons show figures bellow.

Figure 6. Data Training (Process)
from several times the results of training data obtained the results of training data with the best performance on the 10th iteration (repetition) with the results of $1.65 \times 10^{-9}$ performance. With the input data obtained as follows:

3.3.1. Neural Network Training at Normal set temperature conditions

In Table 9 Below, the results of the training data on the standby condition normal temperature with the results obtained in range of $0.000574$ to $0.001$, which means that the input data of the normal set temperature conditions can have a value of 0.

Table 9. Input data sample of normal temperature

| 5.74E-09 | 5.97E-09 | 5.08E-09 | 5.19E-09 | 3.69E-09 |
| 1.02E-09 | 1.45E-09 | 1.14E-09 | 9.18E-08 | 1.12E-09 |
| 1.90E-09 | 1.21E-09 | 2.49E-09 | 7.60E-08 | 2.33E-09 |

3.3.2. Neural Network Training on temperature conditions set Overheat

Table 10 Below, the results of training data obtained on the Over heat temperature conditioning are obtained. Data on the Overheat temperature conditioning obtained results with a range of 0.99 to 1.0, which means that the input data conditions of the normal set temperature can have a value of 1.

Table 10. Sample Value of input data parameters for overheat conditions

| 0.999958 | 0.9998816 | 0.9998716 | 0.9999408 | 0.999976 |
| 0.999970 | 0.9999118 | 0.9999057 | 0.9998960 | 0.999969 |
| 0.999969 | 0.9999766 | 0.9999802 | 0.9999797 | 0.999980 |
| 0.9999253 | 0.9999255 | 0.9999131 | 0.999907 | 0.9999219 |

3.4. Output Data Training

In this step, 10 samples of this data are used to test the Back Propagation Neural Network. From 45 previous training data used as input neurons with each of the 5 samples of standard temperature conditioning and temperature set overheating. Normal temperature, as explained previously, the data value is considered close to 0, and the overheat value is considered 1 or approaching it. The average result of the above error data is $0.08559\%$, the data taken with 16 neurons of 64x45 inputs and the best performance on the 10th repetition

4. Conclusion

From the testing that has been done, the results of this study can be concluded that Implementation of feature extraction using thermography analysis is well applied. The application of the NN method to the prototype system begins with the classification of HSV, where a V value is obtained as a parameter value because there are significant differences in each cell so that the training and testing process can run well with 16 hidden neurons in the 10th iteration and produce system average error of 100%. But in testing, the accuracy decreases by $0.08559\%$ error

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