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Health Monitoring of Induction Motor using Thermal Images

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Abstract

This paper deals with a system which monitors the health condition of a three phase induction motor by using infrared thermal images. Here two systems, real time and off line, are proposed to monitor the temperature variations and analyze the hot regions beyond the rated temperature in the three phase induction motor using infrared thermograms. This system helps to monitor the variation of temperature at the different parts of the induction motor. Abnormal temperature rise in any parts indicates the faults. This technique helps to prevent the parts of induction motor before any catastrophe would happen in the future. The color based segmentation technique is used to identify abnormal hot regions in the thermograms of three phase induction motor. A changing red color intensity algorithm is also implemented to recognize the hot spots and also the change in hotness in a particular area of induction motor to declare the health of that particular area. Similarly the conditions of various areas in the machine all together monitor the overall health of the Induction motor.

Keywords: Feature selection, Fault diagnostics, Health Monitoring, Intelligent system, Thermal image

1. Introduction

Fault detected at the earlier stage at any part of the three phase induction motor may protect the machine from catastrophic failure. Due to that reason early stage detection of fault plays an important role in non-destructive preventive maintenance of three phase induction motor. So early detection of fault could save the machine and as well as protect the system from the total shutdown. Therefore the researchers have taken their interest in the field of health monitoring for the detection of early occurrence of faults of those machine which are widely used in the industry. Particularly in three phase induction motor, different type of bearing faults occur because of the mass unbalance on motor shaft. In such cases, a mechanical load distributed asymmetrically over the shaft, causing displacement of the center of mass of the elements coupled to the motor from the rotation center of the machine[1,2]. This asymmetric distribution generates vibrations and strokes. This unexpected friction produces some of the power loss and that loss is coming out in the form of heat. Similarly in all the faults in the induction motor produce some of the heat in the particular parts of the machine. Different types of faults in induction motors that could be electrical faults or mechanical faults. Electrical faults include different winding faults and rotor faults. Whereas the mechanical faults could be bearing faults and eccentricity faults. In all the above said faults the machine directly or indirectly will gradually produce the heat in the concerned part of the machine. So thermal imaging is one of the pioneer methods to detect the fault at the earlier stage. Now a day, the infrared (IR) thermograph technology has been recognized and accepted as health monitoring method by researchers. Moreover this method is one of the most popular gained more recognized and accepted due to its non-contact and non-destructive features of inspection. It is very quick and trustable monitoring system which can

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monitor the induction motor without any interference to the whole system. In IR thermograph based technique, health monitoring is performed by making the analysis of the thermal images captured by infrared camera. It is very well known fact that durability of any electrical equipment is notably reduced as temperature rises. Infrared (IR) thermograph technology offers many advantages over any conventional methods such as prompt response times, ample temperature ranges, highly reliable, harmless, high spatial resolution, and very lucrative approach for the health monitoring of electrical power systems machinery.

In this research work health monitoring of an induction motor by using infrared (IR) thermograph technology has been developed for both real time and off line application. Continuous monitoring of induction motor gives the real time information, which is useful for health monitoring of running induction motor. On the other side off line monitoring gives the information of standstill contacts which is useful for the health monitoring of other apparatus like fuse cabinet, inductive heating, corrosion, electrical panel and all those which is stand by connected to motor[3–12].

Due to the consequence of liberalization, the new investment in the electrical machinery has come down over past two decades. A lot of Electrical machines specially three phase induction motors have been working well beyond their anticipated life and moreover they are operating under rising stress. As these machines are often exposed to hostile environments during operation this leads to deterioration and hence work beyond the specification. This leads the situation to work under unhealthy condition. As a corollary, new technologies must be exposed to allow electrical machine to better fit under such circumstances and also be economically acceptable and reliable. A good amount of the cost involved in the monitoring of electrical machine to ensure quality and uninterruptable drive system. The equipment on which whole drive system depends is induction motor and the monitoring of induction motor in efficient way is still a big task. In most of the existing health monitoring systems, monitoring of induction motor is done through the current signature analysis. But this technique is tedious and costly procedure to detect faults. Few mathematical models and fuzzy rule based techniques are also now a days popular to detect the health of the motor, but, these techniques are also requires some measured data to interpret and predict. So, the non invasive temperature monitoring of three phase induction motor and its components with less complexity and high reliability is a prime necessity with existing system to overcome the maintenance cost and revenue loss during the fault of the system. The infrared (IR) imaging technique makes non invasive type health monitoring systems for the induction motor which is more reliable for prediction of the health of electrical machine. This IR technique is also useful to monitor the health of any house hold electrical appliances, real time thermal monitoring of power system devices like transformer, measurement of excitation winding temperature in synchronous generator , and real time high temperature measurement in control industry. The design of Visual Inspection System (VIS) based on Charge-Coupled Device (CCD) and Complementary Metal Oxide Semiconductor (CMOS) cameras are already into existence for the monitoring of different processes, objects, sorting, and quality check but designing VIS based on IR cameras for health monitoring system are very rare[1-6].

In most of the papers discussed above, only invasive or pointed temperature is considered and no non-invasive monitoring and controlling systems were proposed in any research. But, in our case, two IR imaging based visual monitoring and controlling systems are proposed: Non Invasive Off Line Visual Inspection System (NIOLVIS) and Non Invasive Real Time Visual Monitoring System (NIRTVMS), for off line and real time applications respectively. The proposed systems have the ability to identify the area of the hotspots in the induction motor and make decisions accordingly to keep other part of the machine healthy. The proposed methods are simulated for a large number of thermogram images of induction motor and performance are analyzed using statistical and geometrical features. This method is executed by using MAT LAB.

2. Thermal Image

2.1 Thermal Image

Infrared camera will not have the ability to measure the body temperature directly of the machine. The camera detectors are very much sensitive to the luminance which is emitted from the object whose photo is to be taken. This luminance is directly proportional to the temperature of that particular object. That kind of image captured by the infrared thermography camera is called thermal image.

This camera is able to capture electromagnetic spectrum within infrared bands, 0.78–1000 μm. A thermal image is a function of radiated energy on an inspected object. This thermal image can be converted into digital form and can be represented in matrix form for computational processing as follows:

$f(x, y)$
$f(0, 0)\, f(0, 1)\ldots\ldots\ldots\ldots f(0, N-1)$
$f(1, 0)\, f(1, 1)\ldots\ldots\ldots\ldots f(1, N-1)$
. . . .
= . . . .
. . . .
$f(M-1, 0)\, f(M-1, 1)\ldots\ldots f(M-1, N-1)$ (1)

2.2 Image Thresholding

Image thresholding is commonly used for the process of image segmentation. Thresholding is also very useful method for the detection of fault of any substance by IRT image. Thresholding is a process to separate objects from its background in a digital image. Histogram is the main tool in this separation process. Say that the grey level corresponds to an image $f(x, y)$ that is composed of lights objects on a dark background, in such a way that object and background pixels have grey levels grouped into two dominant modes. Extracting the object from the background is performed by selecting a threshold T that separates these modes. A threshold image $g(x, y)$ is defined as

$g(x, y)= 1$ if $f\_x, y\_ > T$
0 if $f\_x, y\_ \leq T$

2.3 RGB Colour Model

The RGB (Red Green and Blue) is colour model based on the three basic colours red green and blue. These three colours are mixed together in different amount to produce a broad array of colours. The name of the model comes from the initials of the three additive primary colours red, green, and blue. For the representation and display of images in electronic systems, such as televisions and computers and also in digital cameras RGB colour model is used. In infrared thermal camera also this RGB model is used to display the thermal image. The first experiments with RGB in early colour photography were made in 1861 by Maxwell himself, and involved the process of combining three colour-filtered separate takes. In modern technological era we can analyse the digital image by various methods. A broad area for the researchers is now a digital image processing. We can very easily analyse the image taken by any infrared thermal imaging camera or any simple digital camera by using the MATLAB. We can plot the whole image in a numerical matrix form and easily can identify the each pixel. Each pixel contains three colours red, green and blue as the theory of RGB code. We can identify the intensity of colour of each pixel by the value of individual Red Green and Blue (RGB). MATLAB can be used to calculate the average value of each individual Red, Green and Blue (RGB).we can make any comparison between images. In Infrared thermal imaging camera the temperature is identified based on its colour. The image will be brighter for the higher temperature in the thermal imaging camera. By calculating the average value of Red, Green and Blue (RGB) in a pixel in the thermal image we can detect the hotter place or the hottest place in the image. Even we can identify the hottest pin point and the location of that pixel where the hottest point situated. Here one thermal image of a running induction motor is shown in Figure 1 by using Thermal imaging Camera.

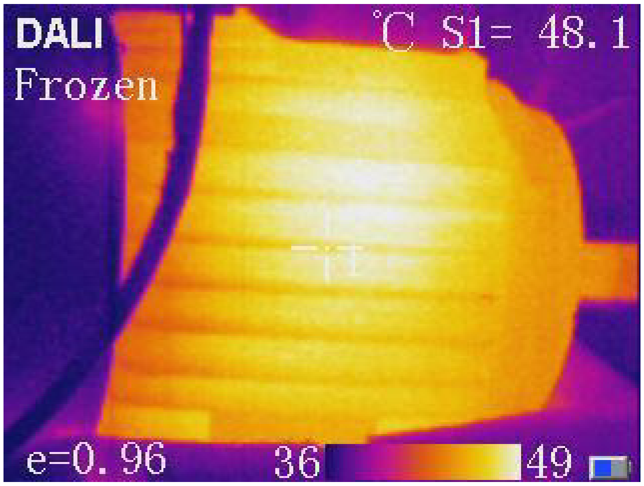


Figure 1. Thermal image of a running induction motor.

3. Experimental Set-Up

A practical set up is developed in Electrical Engineering Research lab at D.E.I. (Deemed to be University) Agra, India. The practical setup consists of Induction motor with the arrangement for creating faults in it. A VIF meter and microphone device is used to acquire the data. The audio signal is acquired with the help of microphone device for both healthy and faulty condition of Induction motor at different loads and at single phasing. Figure 2 shows the practical setup to monitor the health of Induction motor using data acquired from microphone device.

3.1 Test Bench

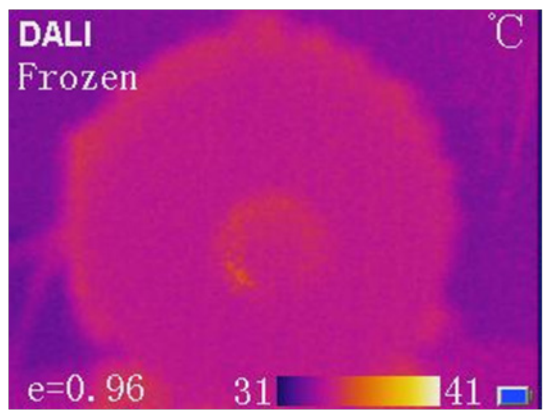
The experimentation is done in Electrical Engineering lab at Dayalbagh Educational Institute (Deemed University) Agra, India. The experiment setup is consisting of one induction motor having a healthy cooling system with the arrangement through which fault in the cooling system can be created. The specification of the motor are three phase Squirrel cage induction motor 230V, 50Hz, 3HP, inbuilt fan type cooling. A voltage-current-frequency (VIF) meter, one infrared thermal imaging camera with a proper fixed camera stand and one computer with MATLAB software installed. The real time image is acquired with the help of infrared thermal imaging camera for both healthy and faulty condition of the cooling system at different load conditions. For both the condition data are sent to computer. MATLAB imports these signals and graphs are drawn for all the parameters at faulty and healthy condition. Graphical analysis is also done for the final declaration of the health condition of the induction motor. Figure 2 shows the experimental setup of health monitoring system of induction motor using infrared thermal imaging camera.

Figure 2. Experimental set-up.

3.2 Infrared Thermal Camera Specification

Used camera specification for the thermal imaging for experimental purpose of induction motor is shown as follow.
Detector type: Uncoiled FPA micro-bolometer.
Array size / format: 160 X 120.
Image characteristics: Field of view / min focus distance: 18° x 13° / 0.3m Spatial resolution (IFOV): 1.9 mrad Thermal sensitivity: ≤ 0.1°C@30°C Frame rate: 50/60 Hz
Focus: Manual Electronic zoom: 2X Spectral range: 8 - 14µm
Image display: LCD: Built-in-high resolution Color 2.5O LCD
Measurement: Temperature ranges: -20°C ~ + 350°C, optional up to +600°C or 1000°C Accuracy: ± 2°C or ± 2 % of reading, whichever is greater. Setup functions: Date / time, temperature unit, language Emissivity correction: Variable from 0.01 to 1.0 Ambient temperature correction: Automatic correction according to user input Atmospheric transmission correction: Automatic correction according to user input object distance, relative humidity, ambient temperature.
Storage mode: Automatic / manual single image saving File format - thermal: JPEG, 14 bit thermal image with measurement data. Laser pointer: Class 2, 1mw / 635nm (red).

4. Experimental Results



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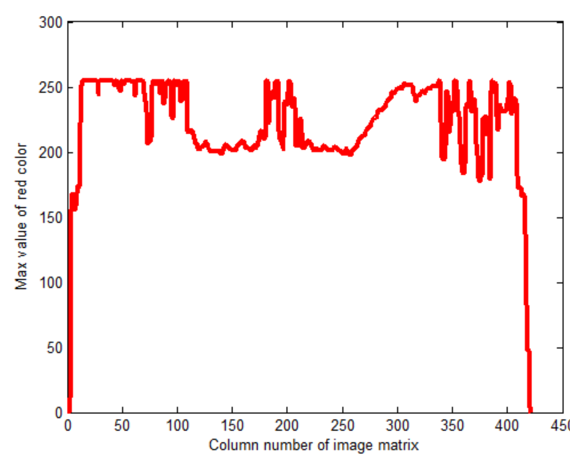

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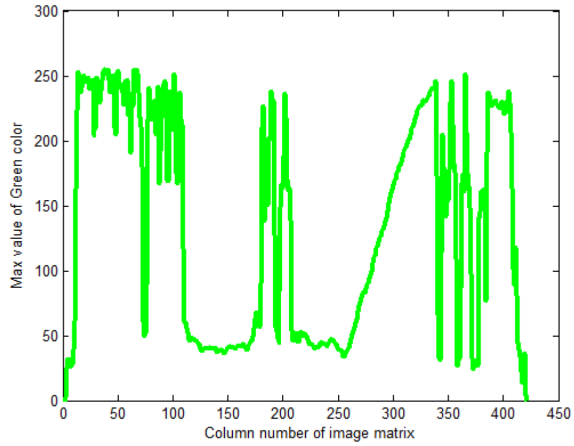

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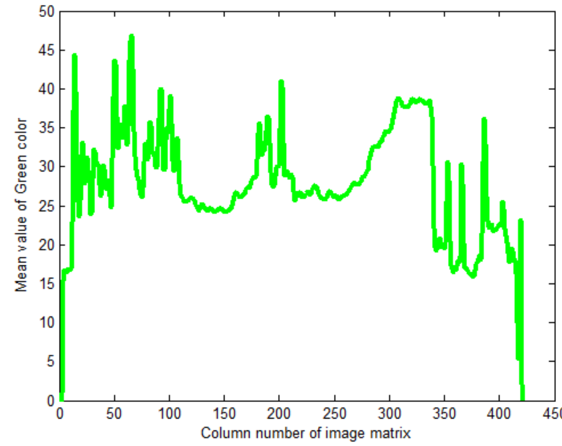

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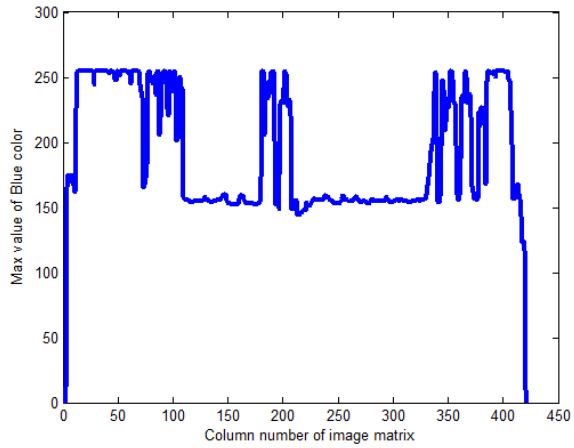

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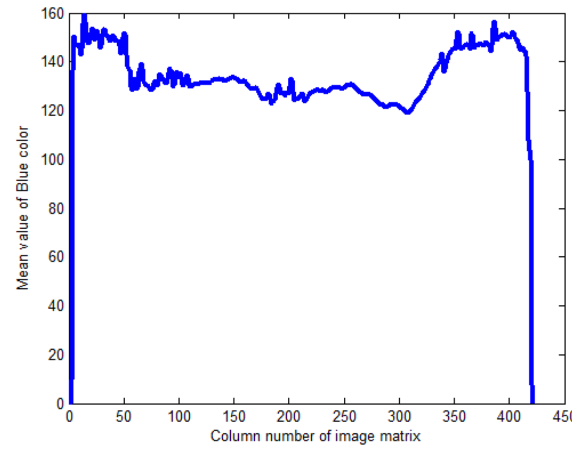

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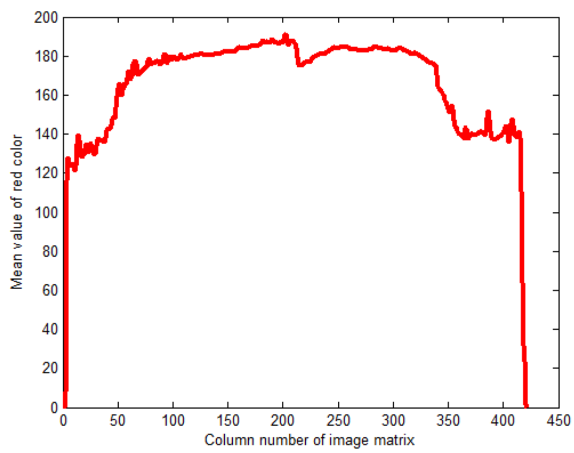
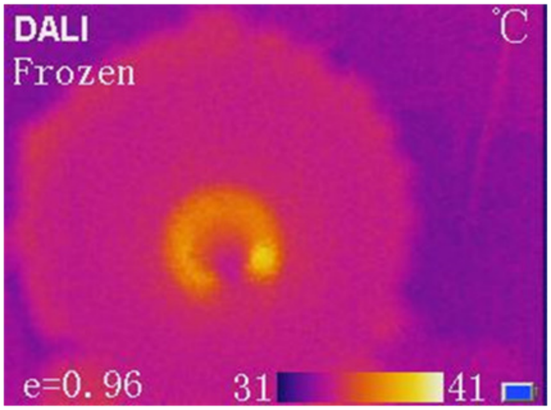


(e)

Figure 3. Analysis of Thermal Image of Healthy bearing Induction Motor (side view). **(a)** Thermal Image of Healthy bearing Induction Motor (side view). **(b)** Max value of Red colour. **(c)** Max value of Green colour. **(d)** Max value of Blue colour. **(e)** Mean value of Red colour. **(f)** Mean value of Green colour. **(g)** Mean Value of Blue colour.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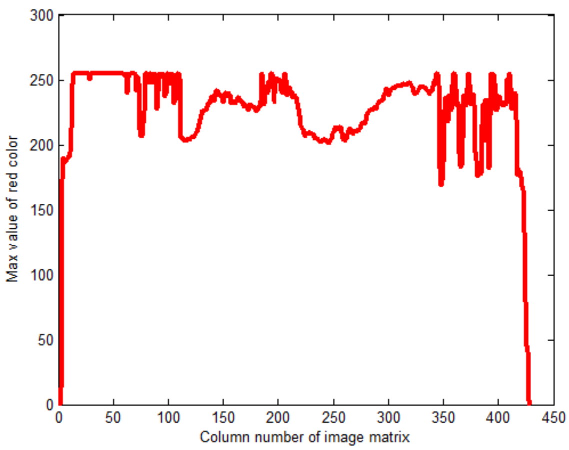
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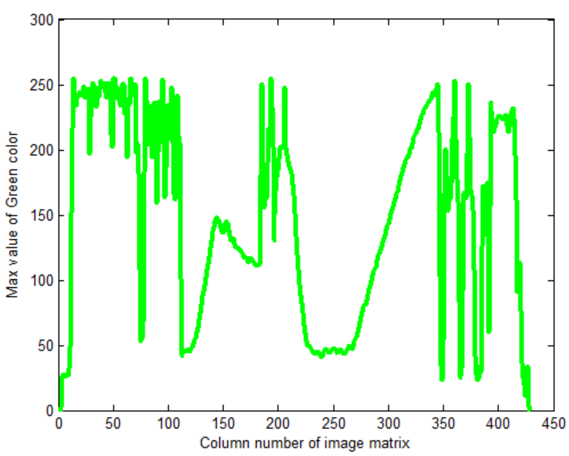
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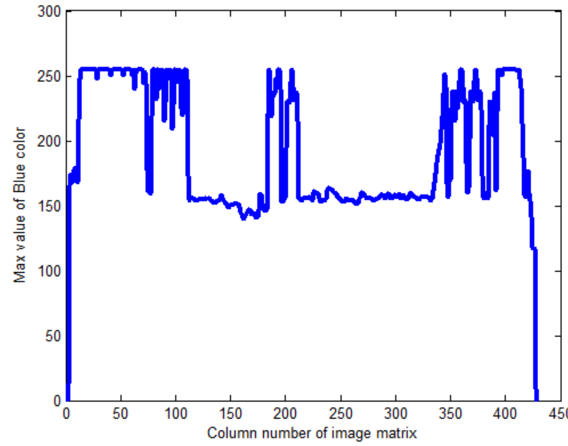
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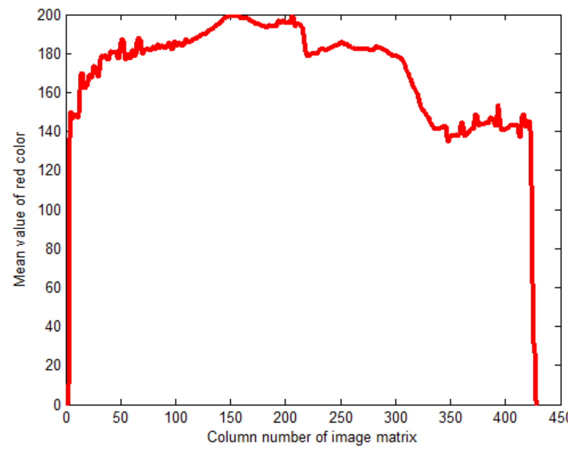
Mean value of red color
Column number of image matrix
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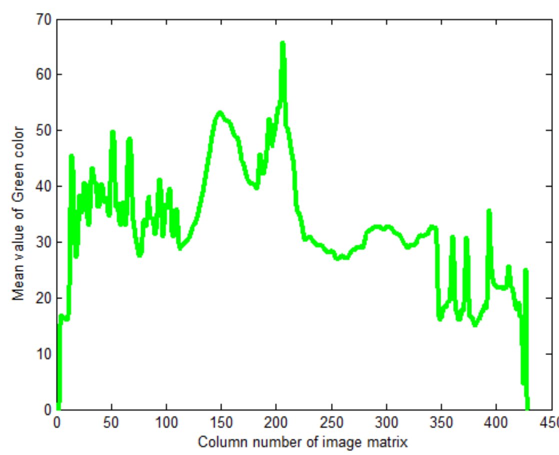
Mean value of Green color
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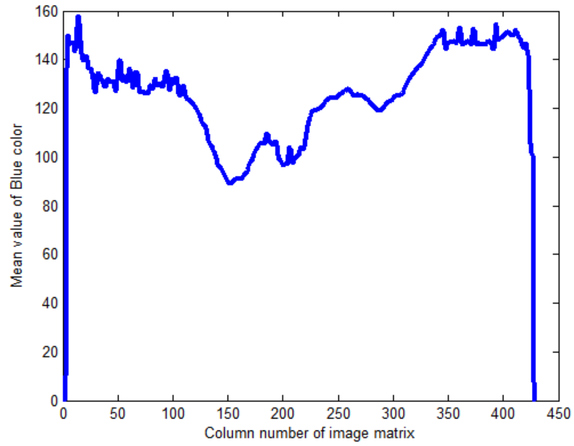
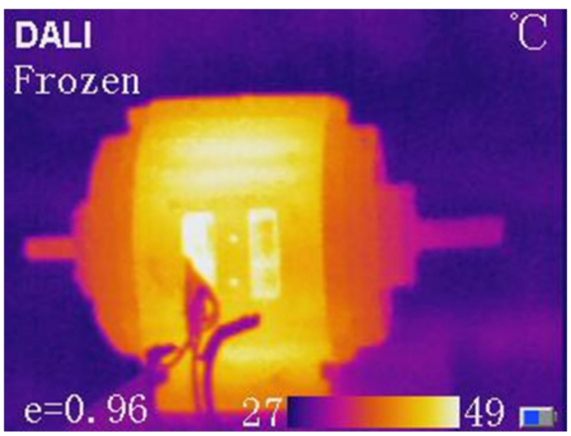


(g)

Figure 4. Analysis of Thermal Image for Bearing fault (defected Ball) of Induction Motor after 10 min. run (side view). **(a)** Bearing fault (defected Ball) of Induction Motor after 5 min. run (side view). **(b)** Max value of Red colour. **(c)** Max value of Green Colour. **(d)** Max of Green Colour. **(e)** Mean of Red Colour. **(f)** Mean of Green Colour. **(g)** Mean of Blue colour.



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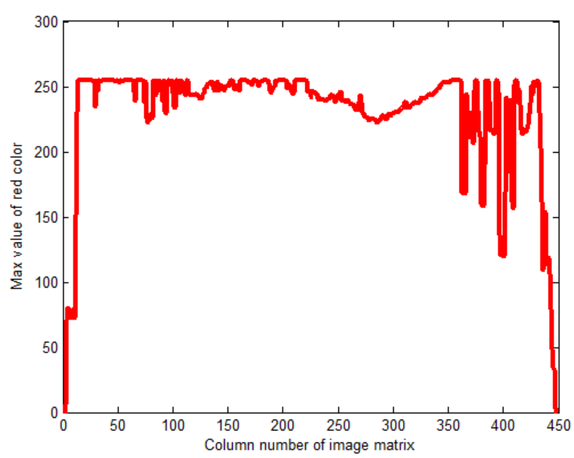

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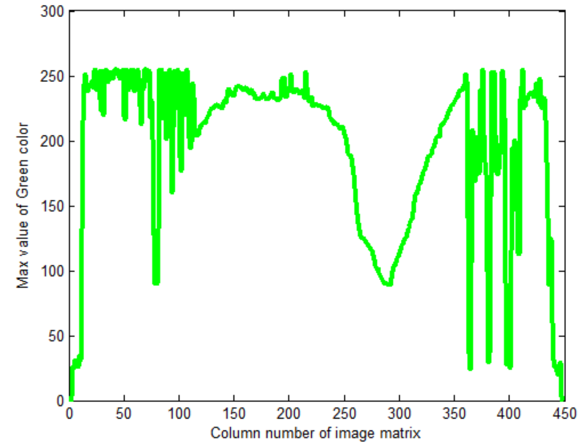

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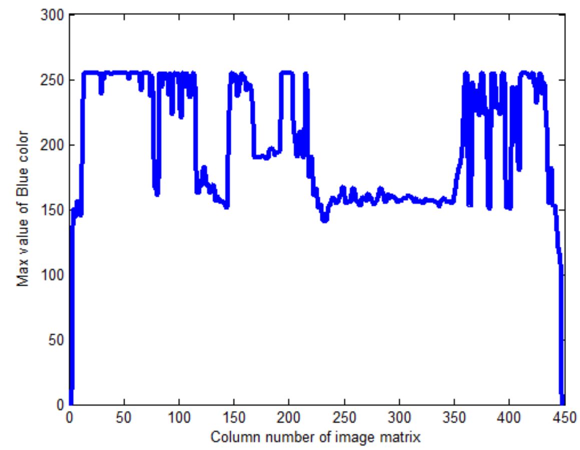

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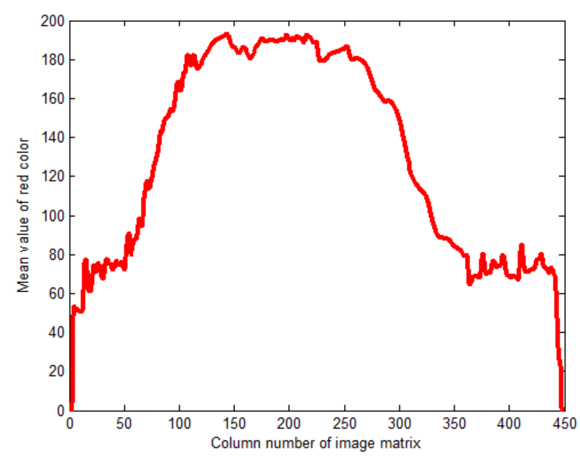

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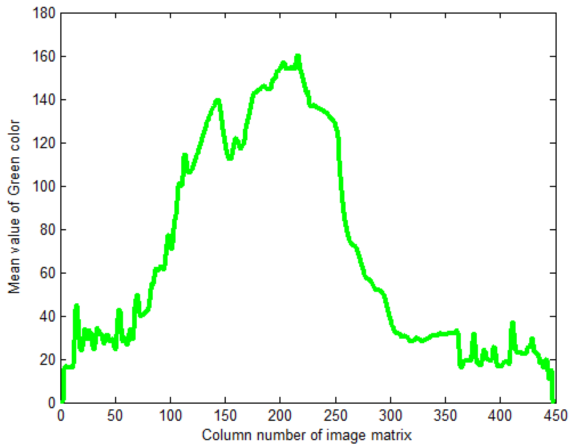

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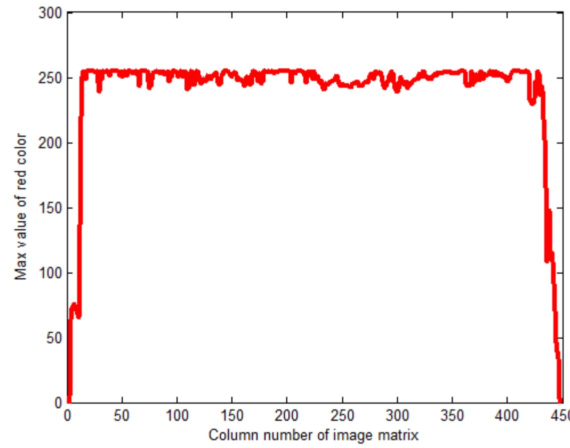

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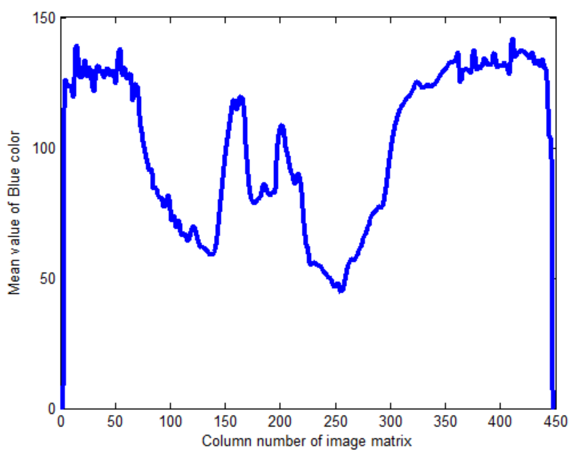

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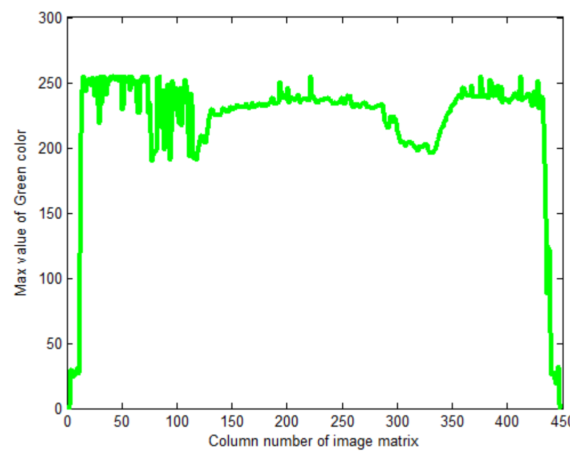

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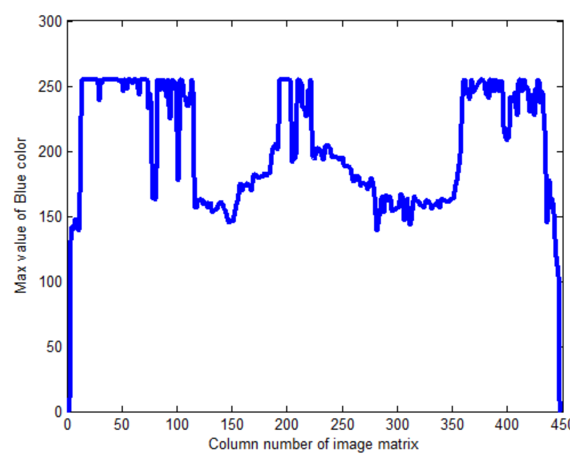
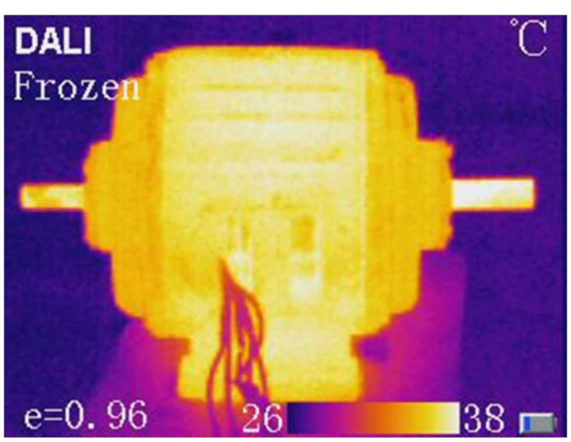


(d)

Figure 5. Thermal Image analysis of Healthy Induction Motor- front view. **(a)** Healthy Bearing of Induction Motor - front view. **(b)** Max value of Red colour. **(c)** Max value of Green colour. **(d)** Max value of Blue colour. **(e)** Mean value of Red colour. **(f)** Mean value of Green colour. **(g)** Mean value of Blue colour.



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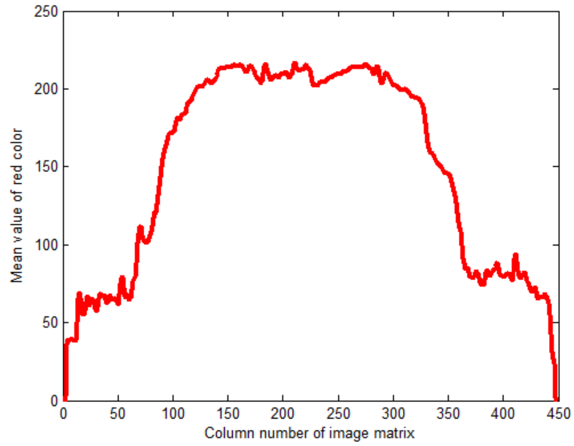

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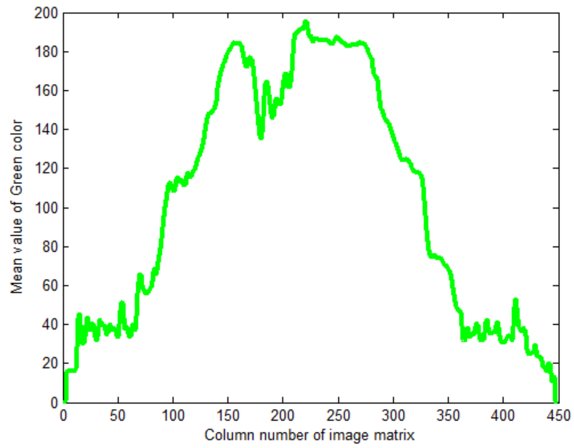

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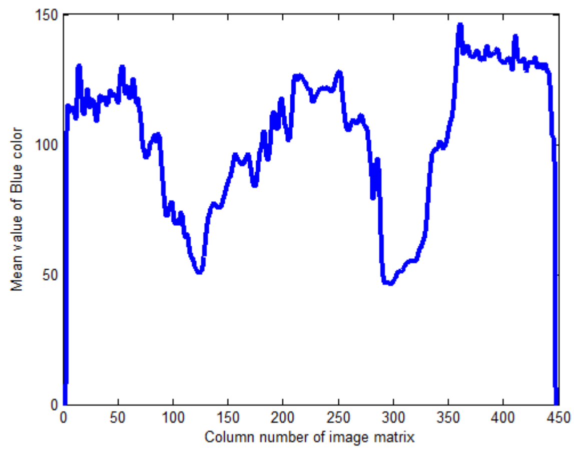

(g)

Figure 6. Image analysis of Faulty Induction Motor - front view. **(a)** Faulty Induction Motor - front view. **(b)** Max value of Red colour. **(c)** Max value of Green colour. **(d)** Max value of Blue colour. **(e)** Mean value of Red colour. **(f)** Mean value of Green colour. **(g)** Mean value of Blue colour.

5. Results and Discussion

The above mentioned Figures 3,4 show that acquired side view of thermal images and Figures 5-6 of front view of thermal images of induction motor under healthy and faulty conditions when bearing fault. These thermal images are analyzed after decomposition in their fundamental colors (such as red, green and blue). The maximum analysis shown in Figures (b, c, d) and mean color analysis shown in Figures (e, f, g) parts. The overall mean of these colors are tabulated in Table 1 and 2 for side view and front view respectively. It is found that the area under curve is very different under healthy condition and faulty motor.

Table 1. Color analysis of induction motor with faulty bearing - side view

	red_mean	green_mean	blue_mean
Healthy Bearing Induction Motor	167.3149	28.1164	134.2076
Faulty motor (after 5 min.)	172.2474	32.5758	126.1543
Faulty motor (after 10 min.)	174.2019	33.0707	125.9828

Table 2. Color analysis of induction motor with faulty bearing - front view

	red_mean	green_mean	blue_mean
Healthy Motor	130.3587	68.4657	101.1839
Faulty Motor	149.8567	103.5122	102.7563

6. Conclusion

The purpose of this paper is to diagnose the health bearing of the induction motor using color analysis technique of thermal images where the induction motor will be monitored without having any physical contacts. Here no sensor is used to get any physical parameters. So the system is very simple and chances of failure are almost nil. It is very much important for an engineer to monitor the induction motor while it is working in a system because any fault generated in induction motor can be the reason of excessive heating. Excessive heat produced in the machine can burn the windings of the motor and the situation will be very harassing. In this method all the sensor which is normally used in conventional monitoring is replaced by an infrared digital camera alone. The system is almost maintenance free and analysis is very particular to the every part as if the whole motor condition is vivid in front of eyes. The analysis results showed that the proposed method is able to monitor the health condition of the induction motor. The method described provides a promising way to establish potential metrics for the description of the health of an induction motor. Therefore, it is desirable to develop an on line health monitoring system for the induction motor based on the above method and realize on-line health evaluation of each part of induction motor. With such a function, the critical failure of induction motor systems can be avoided, and the reliability and efficiency of motor can be increased.

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