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REVIEW ON THERMAL IMAGE PROCESSING TECNIQUES FOR MACHINE CONDITION MONITORING

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ABSTRACT

Infrared thermography or thermal imaging is a very convenient, versatile and non contact method which has been used for many types of physical asset such as electronic component, buildings surveys, and mechanical components and equipments. Infrared thermography was first used for military application but nowadays this technology is used in machine condition monitoring such as fault detection, identification as well as for fault diagnose .This paper presents a survey on different thermal imaging techniques for fault detection and diagnose based on the object temperature.

Key words: Infrared Thermography, Thermal Imaging, Emissivity, Heating, Thermal Image.

1. NOMENCLATURE

Q_{rad}	Radiated heat by object
A	Surface Area (m^2)
σ	Stefan- Boltzmann constant ($5,67\cdot10^{-8}$ $W/m^2/k^4$)
ξ	Emissivity (0, 1)
T_s	Surface temperature (K)
T_{refl}	Reflected temperature (K)
$P_{(g)}$	Histogram probability
$N_{(g)}$	Total no. of gray scale Level in an image I
M	No. of pixels in an image
I	Input image
S	Skew
E	Energy
E_t	Entropy
σ_g	Standard Deviation

2. INTERDUCTION

Condition monitoring of mechanical machinery or any component of a machine has become challenging and important task for the identification of different machine condition which can effect productivity, quality and cost for the industry. The maintenance of critical assets in industries has significant impact to each industry. Among the excellent condition

monitoring tools, infrared thermograph (IRT) has a variety of practical applications in industry, construction, police, rescue operations, border patrol, human and veterinary medicine, animal husbandry, biology, and ecology.IRT allows for inspection of mechanical machinery for thermal pattern on pump, motors, bearings, fans, pulleys and other rotating machinery [1][2]. To ensure that a continuous power supply which are input to the electrical component, the reliability of electrical power equipment must be checked regularly for normal operation of machine or any component of a machine. Abnormality in any part of the electrical equipment will occur when their internal temperatures exceed their limits which can lead to the failure of a certain machine or element.

Infrared thermography is a non-contact and non-intrusive temperature measuring technique with an advantage of no alteration in the surface temperature and capable of displaying real time temperature distribution. Any object that has a temperature above absolute zero (-273^{o}C) emits infrared radiation.

Radiation that is emitted by any object does not need the presence of a medium. Heat-transfer process are mainly focused on thermal radiation, which is a type of radiation emitted by the bodies due to their temperature; it represents the difference between the amount of energy absorbed and transmitted by the body. Stefan- Boltzmann´s law gives the heat transfer through radiation. The equation is as follows:

$$Q_{rad} = A \cdot \sigma \cdot \xi \cdot (T_s^4 - T_{refl}^4)$$

Where
Q_{rad} = Radiated heat by object
A = Surface (m^2)
σ = Stefan- Boltzmann´s constant ($5{,}67 \cdot 10^{-8}$ $W/m^2/k^4$)
ξ = Emissivity (0, 95)
T_s = Surface temperature (K)
T_{refl} = Reflected temperature (K)

For thermal image analysis, special equipment is used which is known as Thermal Camera. A thermal camera detects infrared radiation emitted from objects that have temperature above absolute zero or -273°C. An infrared camera detects infrared energy emitted from object, converts it to temperature, and displays image of temperature distribution. The use of thermal imaging or infrared thermography has become an important tool in preventive and predictive maintenance [3][4].

3. IR THERMOGRAPHY FOR MACHINERY

IR device can detect the thermal abnormality of machine when there is any rapidly overheating component on machinery. The total radiation that goes through the optics of infrared camera (Figure1) [5] consists of the emitted radiation from the object itself and the reflected radiation from the surroundings. And that's why we need to set up the right emissivity and reflected apparent temperature, other air related parameters for temperature reading.

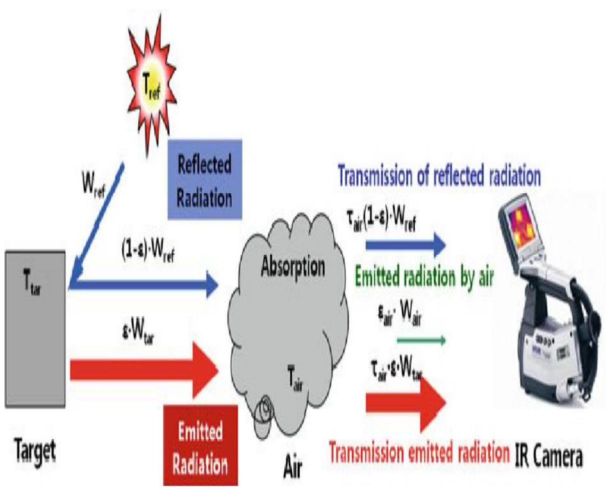

Figure1. Schematics of the total radiation go through the IR camera

4. THERMAL IMAGE ANALYSIS

Image Histogram and Image Filtering:

Histograms are widely used in the first step of thermal image processing. An image is assumed to be a rectangular matrix of discretised data (pixels) pix [p, q], where *p*=0, 1… P, *q*=0, 1…Q. Each pixel takes value from the range $i \in <0, N(g) \div 1>$. We will use N(g) as total number of gray level available range from 0 to 256 for image but for thermograph signature which is comparable with maximum and minimum temperature as may be mentioned 0^0 K to maximum value of temperature. The histogram describes the frequency of existence of pixels of the same intensity in whole image or in the region of interest (ROI).For an image I, the first-order histogram probability *P(g)* can be expressed as:

$$P(g) = \frac{N(g)}{M}$$

Where *M* is the number of pixel in the image I and *N(g)* is the number of gray level *g*. Histogram gives global information on the image. By converting histogram we can obtain some very useful image improvement, such as contrast enhancement [6][7][8]. Figure2 [5] and figure3 shows the image of an induction motor and its corresponding histogram. For thermal image the gray scale level of an image depends on temperature and that gray scale level always varies with temperature.

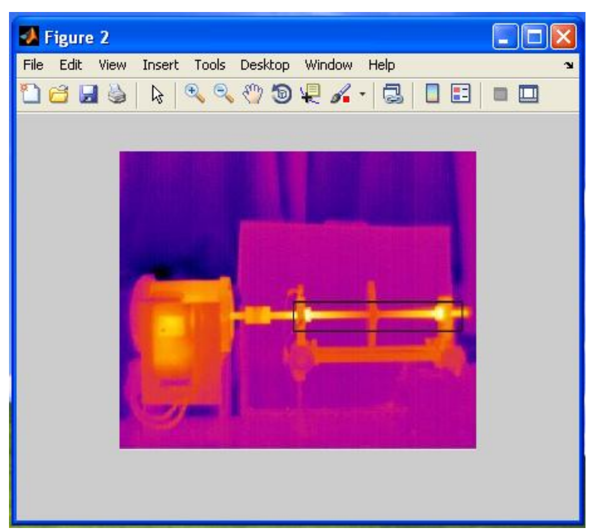

Figure2.Thermal image of an induction motor

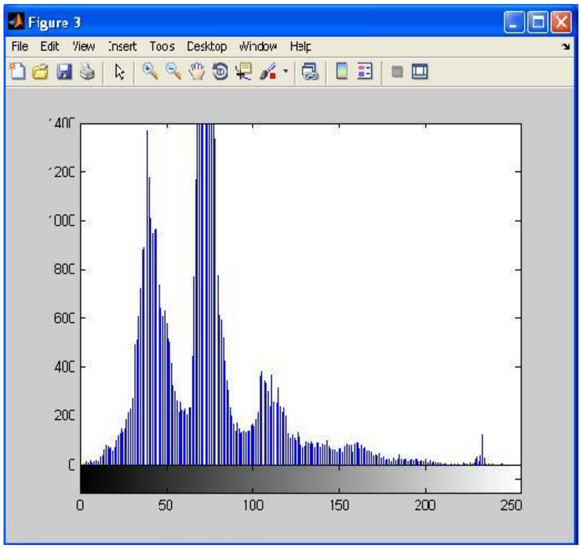

Figure3. Corresponding Histogram of Fig2

One of the methods for contrast enhancement and proper edge filtering is based on statistical differencing, where each pixel value is scaled by the standard deviation calculated in its neighborhood, as below:

$$G(i,j) = \frac{F(I,j)}{S(I,j)}$$

Where: *F(i,j,), S(i,j,)* denote the original pixel value and standard deviation, respectively. Figure 4 shows the value of pixels of center point based on the standard deviation. The standard deviation equation is given by:

$$\sigma_g = \sqrt{\sum_{g=0}^{L-1} (g-\bar{g})^2 P(g)}$$

Image is first converted into gray scale and then standard deviation is calculated. The value of standard deviation is 34.2.

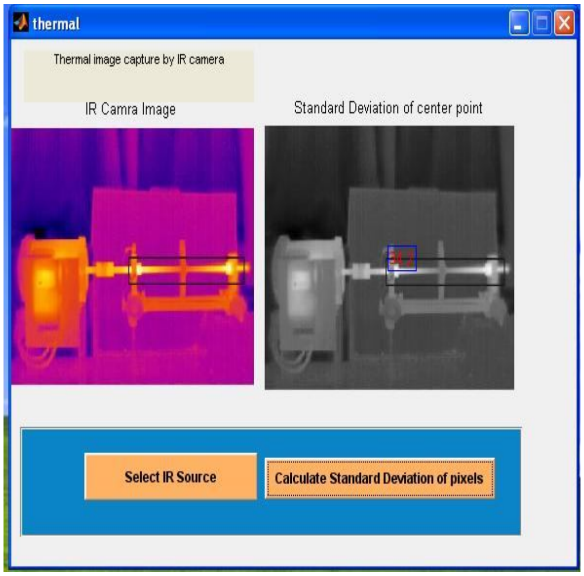

Figure4. Standard Deviation of image center point

The standard deviation, which is also known as the square root of the variance, tells us something about the contrast. It describes the spread in the data, so a high contrast image will have a high temperature distribution over image. Using this we can be able to classify various of machine conditions thermal images. The higher standard deviation causes the lower pixel value. It means that the part of the image with low color or luminance variation will be enhanced, and more image details are visible.

5. WAWELET TRANSFORMATION OF IMAGE

Wavelet transform is actually used in many domains, such as telecommunication and signal processing e.g. for compression. In image processing it can be employed to get new features, representing both global and detail information. Wavelet transformation is based on image filtering represented by rows and columns using low and high pass linear filters (Figure 5).

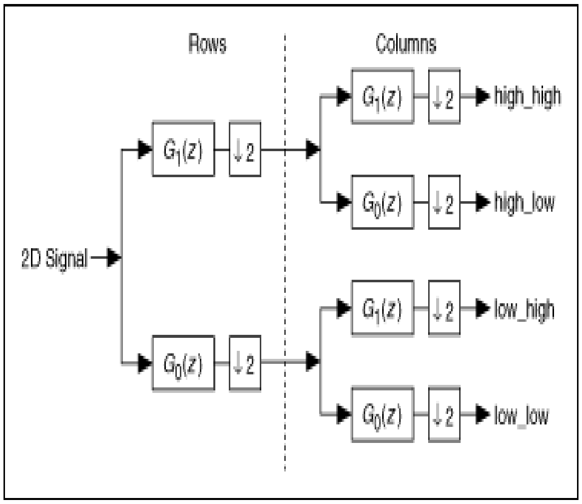

Figure5. Discrete Wavelet Transformation of a signal

After filtering, the decimation is used to reduce number of pixels.

6. FEATURE BASED DIAGNOSIS WITH THERMAL IMAGES:

The traditional condition monitoring and fault diagnosis is composed with data acquisition, data pre-processing, data analysis and decision making (Figure6)[5]. Important features contain in the signal can be extracted for machine condition monitoring and fault diagnosis. The feature based expert system is usually data acquisition, data pre-processing, feature extraction, feature selection and classification in very similar form of human version diagnosis

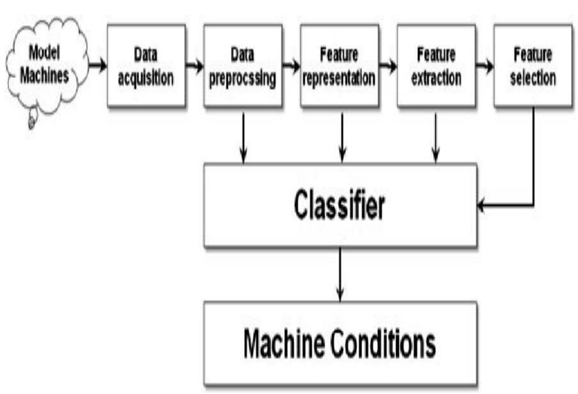

Figure6. Flow chart of feature based fault diagnosis system

Some of the statistical features from the image histogram can be obtain such as:

- Standard deviation tells us about the contrast of the Image. The standard deviation equation is given by:

$$\sigma_g = \sqrt{\sum_{g=0}^{L-1} (g - \overline{g})^2 P(g)}$$

- The mean is the average value which gives some information about general intensity (or brightness) of the image. Mean can be defined as follows:

$$\overline{g} = \sum_{g=0}^{L-1} gP(g) = \sum_{r} \sum_{c} \frac{I(r,c)}{M}$$

- Skewness measures the asymmetry about the mean in the gray level distribution. The skew S measures the asymmetry about the mean in the gray level distribution. It is defined as:

$$S = \frac{1}{\sigma_g^3} \sqrt{\sum_{g=0}^{L-1} (g - \overline{g})^3 P(g)}$$

- The energy for an image describes how the gray level in an image is distributed. The range of energy for an image can range from [0,1]. Energy can be defined as:

$$E = \sum_{g=0}^{L-1} [P(g)]^2$$

- The entropy E_t is a measure that tells us how many bits are need to code the image data. As the pixel values in the image are distributed among more gray levels, the entropy will increases.

$$E_t = \sum_{g=0}^{L-1} P(g) \log_2 [P(g)]$$

- The kurtosis K is just the ratio of the fourth central moment and the square of the variance.

$$K = \sum_{g=0}^{L-1} \frac{(g - mean)^4}{\sigma^4}$$

7. IMAGE CLASSIFICATION AND MACHINE CONDITION DIAGNOSIS METHODS

Artificial Neural Network (ANN) can be used for classification. The selected image features has been used as inputs. It means that the number of inputs nodes is equal to number of the considered features. Number of neuron in the first hidden layer can be equal or lower than the number of features in the classification, as shown in Figure 7. ANN can have user-defined next hidden layers which allow additional nonlinear processing of the input features. As ANN is the nonlinear system, such technique allows additional decor relating and data reduction, what finally improves the classification. Such approach is known as Nonlinear Discriminant Analysis (NDA) [8][9][10].

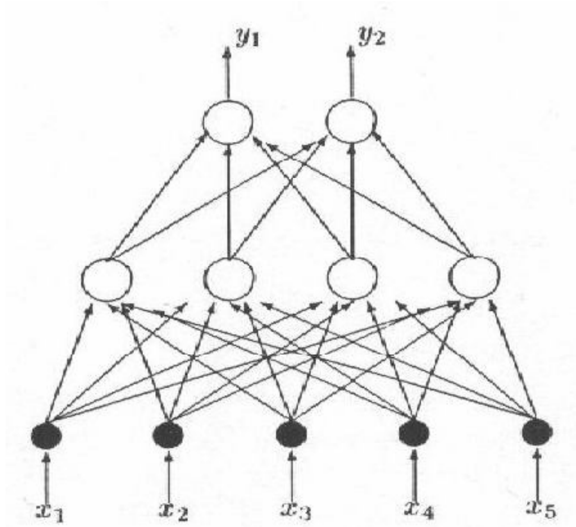

Figure7. Neural network example with input, single hidden and output layers

8. CONCLUSION

In this work infrared thermography (IRT) technique for machine condition monitoring and different thermal image processing techniques are discussed. Histogram features based on statistical of image were employed as a proper feature for thermal image data and based on these statistical data thermal image are analyzed.

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