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Fault diagnosis in electrical and electronic equipments using thermography and image processing-a survey

Swapnil P. Parmar[1], Prof. D. H. Shah[2]
[1]*PG Student, Instrumentation and control department, LDCE Ahmedabad,Gujarat, India*
[2]*Associate professor, Instrumentation and control department, LDCE Ahmedabad,Gujarat, India*

Abstract- **The paper presents the application of infrared thermography (IRT) and image processing for assessing and monitoring electrical components. Overloading, load imbalance, corrosion and loose connection of electrical components can produce a thermal anomaly or hot spot. The abnormality of the components will occur when its internal temperature reached beyond its limits. An infrared camera is a device that records such radiations emitted and the intensity of such radiations shall represent the temperature of the source emitting those radiations. The image captured using Infrared camera is processed using Matlab and image processing tool to detect the temperature of the hot spot without direct contact measurement.**

Index Terms- **Infrared thermography(IRT),infrared camera, Matlab, image processing tool.**

I. INTRODUCTION

Infrared thermography is a non-contact and nonintrusive 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' 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:

$$Q_{rad} = A\sigma\xi(T_s^4 - T_{refl}^4) \quad \text{……………………..} (1)$$

Where,

Qrad = Radiated heat by object
A = Surface (m2)
σ = Stefan- Boltzmann´s constant (5.67×10^{-8} W/m^2/k^4)
ξ = Emissivity
Ts = Surface temperature (K)
Trefl = Reflected temperature (K).

Image processing is a method to convert an image into digital form and perform some operations on it, in order to get an enhanced image or to extract some useful information from it. It is a type of signal dispensation in which input is image, like video frame or photograph and output may be image or characteristics associated with that image. Usually Image Processing system includes treating images as two dimensional signals while applying already set signal processing methods to the .

Applications of image processing:

- Interest in digital image processing methods stems from two principal application areas:
  - ✓ Improvement of pictorial information for human interpretation, and
  - ✓ Processing of scene data for autonomous machine perception.
- In the second application area, interest focuses on procedures for extracting from image information in a form suitable for computer processing.

Examples include automatic character recognition, industrial machine vision for product assembly and inspection, military recognizance, automatic processing of fingerprints etc[1][2].

II. EXPERIMENTAL METHODOLOGY

Haoyang Cui, Yongpeng Xu, Jundong Zeng and Zhong Tang presents "The Methods in Infrared Thermal Imaging Diagnosis Technology of Power Equipment". Infrared diagnosis system must solve the problems about instrument accuracy, image analysis and fault classification. In view of the above, this paper focus on the description of hotspots, difficulties and future trends in infrared thermal image processing, intelligent fault diagnosis research.

At present, the intelligent diagnosis system of thermal infrared images in electrical equipment usually consists of five main steps, as shown in Figure 1.

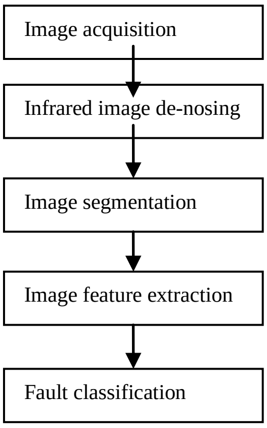

Fig 1. Steps of intelligent diagnosis system

De-noising methods: 1.Single de-noising algorithm, 2.Multiple de-noising algorithms. Image segmentation methods can be divided into: threshold segmentation method, region segmentation method, edge detection method etc. in intelligent fault diagnosis system neural networks have characteristics of parallel processing, learning and memory, nonlinear mapping and adaptive ability, they are obvious useful in the aspect of electrical equipments fault diagnosis. The neural network consists of self-organizing neural network, feed-forward neural network and support vector machine neural network model. The application of feed-forward neural network is the most extensive, which can be divided into back propagation network (BP network), radial basis function network (RBF network)[3].

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 2. 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 Discriminate Analysis (NDA) [3][4][5][6]

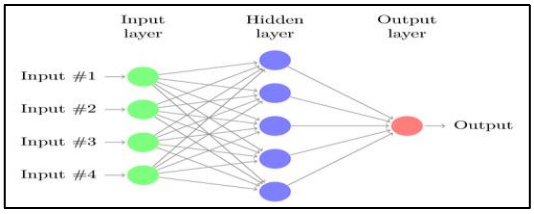

Fig 2. Artificial neural network

Jibu Varghese k, Tripty Singh, Sreyas Mohan presents "PCB Thermal Image Analysis using MATLAB". The Thermal image of PCBs is taken using IR cameras. In this work, series of 20 thermal images stored in .png form. These are the images of the same PCB in different thermal load conditions. Each image corresponds to a particular electrical maneuver. To analysis the images MATLAB based tool is made, which is identify the images having the maximum area of the peak temperature using Histogram Thresholding based segmentation of the images[7].

Histogram thresholding for image segmentation

Image segmentation algorithms are based on one of two basic properties of intensity values discontinuity and similarity. Based on abrupt changes in intensity, divide an image. Second type is based on dividing an image into regions that are similar according to some criteria. Histogram Threshold approach comes under this. Threshold is one of the widely used methods for image segmentation. It is useful in differentiating foreground from the background. While choosing a proper threshold T, the gray level image can be changed to binary image. The converted image contains all of the actual knowledge about the position and shape of the objects of interest (foreground). The benefit of obtaining primary a binary image is that it reduces the complexity of the data and simplifies the process of recognition and classification. The general way to convert a gray-level image to a binary image is to select a single threshold value (T). Then all the gray level values below this T will be classified as black (0), and those above T will be white (1)[7].

Ying-Chieh Chou Leehter Yao presents"Automatic Diagnosis System of Electrical Equipment using Infrared Thermography". Based on the principle of Otsu's statistical threshold selection algorithm using gray-level histograms . The reason for using this algorithm on power facilities is their equipment always have temperatures higher than the environment. By using a thresholding method, the image of the main object can be separated from its background[8].

If g(x, y) is a threshold version of f(x, y) at some global threshold *T*, it can be defined as,

$$g(x, y) = 1$$

if f(x, y) ≥ T = 0, otherwise………………….. (2)

Thresholding operation is defined as:

T = M [x, y, p(x, y), f (x, y)]…………………..(3)

Otsu method

In Otsu's method we exhaustively search for the threshold that minimizes the intra-class variance (the variance within the class), defined as a weighted sum of variances of the two classes[8][9]:

$$\sigma_w^2(t) = q_1(t)\sigma_1^2(t) + q_2(t)\sigma_2^2(t) \quad \text{………… (4)}$$

Where the class probabilities are estimated as:

$$q_i(t) = \sum_{i=1}^{t} P(i) \quad \text{…………………………….. (5)}$$

Finally, the individual class variances are:

$$\sigma_1^2(t) = \sum_{i=1}^{t} [i - \mu_1(t)]^2 \frac{P(i)}{q_1(t)}$$

$$\sigma_2^2(t) = \sum_{i=t+1}^{I} [i - \mu_2(t)]^2 \frac{P(i)}{q_2(t)} \quad \text{…………….. (6)}$$

After some algebra, we can express the total variance as...

$$\sigma^2 = \sigma_w^2(t) + q_1(t)[1 - q_1(t)][\mu_1(t) - \mu_2(t)]^2 \quad \text{……… (7)}$$

Ms. Chaitali R. Wagh , Mr. Vijay B. Baru presents "Detection of Faulty Region on Printed Circuit Board With IR Thermography". Principal component thermography technique use to process the IR image sequences obtained from testing composite structures to enhance the contrast of acquired images. The Principal component analysis (PCA) applied on thermographic image data is called as Principal Component Thermography (PCT). The proposed PCT is a statistical analysis tool applied to multivariate data. The method helps to reduce the unwanted noise levels present in the captured image sequences and increase the contrast of the processed images compared to unprocessed data. Here use a set of orthogonal statistical modes to enhance the contrast of the captured thermal images. The SVD base PCA is used to actual PCT due to the volume of image data captured in a single thermographic experiment[11].

Basics of singular value decomposition

Singular Value Decomposition (SVD) is said to be a significant topic in linear algebra by many renowned mathematicians. SVD has many practical and theoretical values; special feature of SVD is that it can be performed on any real (m, n) matrix. Let's say we have a matrix *A* with *m* rows and *n* columns, with rank *r* and $r \le n \le m$. Then the *A* can be factorized into three matrices:

$$A = USV^T \quad \text{…………………………………… (8)}$$

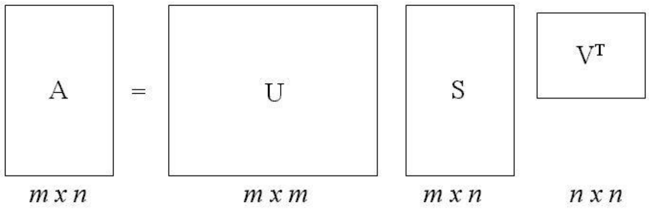

Fig 3. Illustration of Factoring *A* to *USV*^T

Where Matrix *U* is an $m \times m$ orthogonal matrix

$$U = [u_1, u_2, ...u_r, u_{r+1}, ...u_m] \quad \text{………….. (9)}$$

column vectors $\mathbf{u_i}$, for $i = 1, 2, \ldots, m$, form an orthonormal set:

$$u_i^T u_j = \begin{cases} 1 \ldots\ldots i = j \\ 0 \ldots\ldots i \neq j \end{cases} \quad \text{……………………….. (10)}$$

and matrix v is n*n orthogonal matrix

And matrix *V* is an $n \times n$ orthogonal matrix

$V=[v_1,v_2,\ldots\ldots v_r,v_{r+1},\ldots..v_n]$………………… (11)

Column vectors v_i for i= 1,2,…..n form an orthogonal set

$$v_i^T v_j = \delta = \begin{cases} 1 \ldots\ldots i = j \\ 0 \ldots\ldots i \neq j \end{cases} \quad \text{………………….. (12)}$$

Here, *S* is an $m \times n$ diagonal matrix with singular values (SV) on the diagonal. The matrix *S* can be showed in following:

$$s = \begin{pmatrix} \sigma 1 & 0 & 0 & 0 \\ 0 & \sigma 2 & \cdots & 0 \\ 0 & 0 & \cdots & \sigma r + 1 \\ 0 & 0 & 0 & \sigma n \end{pmatrix} \quad \text{…………… (13)}$$

For $i = 1, 2, \ldots, n$, S_i are called Singular Values (SV) of matrix *A*.

The feature extraction of the thermal image is acquired from the designed system setup and fed to the Euclidian distance for fault diagnosis and identification[10].

Malge P.S. Nadaf R.S. presents "PCB Defect Detection, Classification and Localization using Mathematical Morphology and Image Processing Tools". Images are segmented into primitive patterns using morphological techniques such as dilation, erosion, opening, and closing. The windowing technique is used to enclose the segmented pattern in a compact window with an assigned coordinate which helps in partitioning the inspection tasks among multiple processors for faster on-line processing, and associates certain types of defects with certain basic pattern, thus making inspection easier.

The binary images are fed into the image processing algorithm using MATLAB image processing tools. The algorithm uses operations such as NOT, X-OR and IMFILL. NOT operation inverts the binary values of template and test images for each segment. XOR is used for image subtraction. Positive image is the result of subtracting the test image from the template image and the negative image is the result of subtracting the template image from the test image[12].

T. J. Ramırez-Rozo, J. C. Garcıa-A lvarez, C. G. Castellanos-Domınguez presents "Infrared Thermal Image Segmentation using Expectation-Maximization-based Clustering". Proposed segmentation method uses the expectation maximization algorithm (EM-Algorithm), which is an iterative process that estimates maximal likelihood when missing or hidden data is present; to know the model parameter set that fits the data. The EM-Algorithm consist of two steps, repeating until a criterion of convergence is reached; the first step is called expectation step (E-step) consists of a missing data estimation given the observed data and current estimated parameters; the second step, called maximization step (M-step) consists of maximizing the likelihood function, by assuming the knowledge of missing data as the estimated data found in previous step. The convergence is carried out when the maximal difference between estimated parameter values of E-step and M-step is achieved.

Expectation maximization (EM algorithm)

Let **X** be the data vector. We want to know the parameter θ such that the maximal likelihood of estimate θ, $P(\mathbf{X}|\theta)$ is achieved. In order to estimate θ we use the log likelihood function defined as[5]:

$$L(\theta) = \ln P(\mathbf{X}|\theta) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

Where $L(\theta)$ is the likelihood function defined as a function of parameter of θ. Since $\ln P(\mathbf{X}|\theta)$ is a strictly increasing function, the value of θ that maximizes $P(\mathbf{X}|\theta)$ also maximize $L(\theta)$. Since EM-Algorithm is an iterative process for maximizing $L(\theta)$, after nth iteration the current estimate of θ is given by θn. Consequently, we want to compute an updated estimate of θ such that $L(\theta) > L(\theta n)$. Likewise, we want to maximize the difference[13].

$$L(\theta) - L(\theta n) = \ln P(\mathbf{X}|\theta) - \ln P(\mathbf{X}|\theta n)) \ldots\ldots\ldots(15)$$

Considering the missing data as the random vector **Z** and a given realization by **z** the Eq. 2 can be rearranged as

$$L(\theta) - L(\theta n) = \ln \textstyle\sum_z (P(\mathbf{X}|\mathbf{z}, \theta)P(\mathbf{z}|\theta) - \ln P(\mathbf{X}|\theta n)) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(16)$$

So, the EM-Algorithm uses arguments of Equation 3 as follows

1) E-step: Determining the conditional estimation of $E\mathbf{Z}|\mathbf{X},\theta\mathbf{n}\ \{\ln P(\mathbf{X}, \mathbf{z}|\theta)\}$

2) M-step: Maximize this expression respect to θ Likewise, EM-Clustering has the same principle of EM Algorithm, using image elements (pixels) as processed data, and the clustering of pixels are given by the initialization of the original data. This initialization consists of an untrained classifier mapping, used to update the labels of the initially dataset iterating the following steps:

1) Trained Mapping: The classifier is trained with the training dataset obtaining a trained map.

2) Reliable Dataset: Dataset is relabeled accordingly the trained map obtained in Trained Mapping step. The convergence criterion is reached when labels keep unchanged for the next iteration.

Thermal IR image segmentation is an important task that takes place in several NDT&E analysis. Fault diagnosis can be achieved from a proper segmentation using pattern recognition algorithms, since the thermal image of a machine can give us very important information about machine's condition[13].

III. CONCLUSION

Computerized diagnosis system is developed to inspect electrical equipment using infrared thermography and image processing to identify fault. the application of modern image processing and thermography along with a artificial intelligence based approaches can further augment the decision making process faster and without human interference.

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