MONITORING AND FAULT DIAGNOSIS OF ELECTRICAL INSTALLATION USING THERMAL IMAGING

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MONITORING AND FAULT DIAGNOSIS OF ELECTRICAL INSTALLATION USING THERMAL IMAGING

by

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LIST OF ABBREVIATIONS

ACT	Active Thermography
CACHE	Contrast Accumulated Histogram Equalization
CDF	Cumulative Distribution Function
CLAHE	Contrast Limited Adaptive Histogram Equalization
CWT	Continuous Wavelet Transform
DWT	Discrete Wavelet Transform
FFT	Fast Fourier Transform
GLCM	Grey Level Co-occurrence Matrix
HE	Histogram Equalization
HSI	Hue, Saturation and Intensity
IRT	Infrared Thermography
LM	Levenberg-Marquardt
MATLAB	Matrix Laboratory
MLP	Multilayer Perceptron
PSD	Power Spectral Density
ROI	Regions of Interest
SCG	Scaled Conjugate Gradient
TIC	Thermal Imaging Camera

PEMANTAUAN DAN DIAGNOSIS KEGAGALAN PEMASANGAN ELEKTRIK MENGGUNAKAN IMEJ THERMAL

ABSTRAK

Kerosakan elektrik merupakan arus elektrik yang tidak normal melencong beban biasa. Kamera termal telah digunakan secara meluas bertahun-tahun untuk memantau dan memeriksa kerosakan termal peralatan elektrik dengan mengesan titik panas. Walau bagaimanapun, analisis manual imej inframerah untuk mengesan kerosakan dan mengklasifikasikan status peralatan mengambil masa yang panjang dan usaha, dan juga menyebabkan keputusan diagnosis yang salah. Untuk menangani masalah ini, teknik pemprosesan imej diperkenalkan untuk menganalisia kerosakan elektrik yang mungkin secara automatik dari imej inframerah. Dalam projek ini, kaedah Otsu, penyaringan Wiener dan penyamaan histogram dilaksanakan dalam menganalisis kerosakan elektrik. MATLAB dipilih sebagai platform untuk membangunkan algoritma untuk memproses imej inframerah. Pada peringkat pertama, imej inframerah akan dimuat naik ke komputer untuk menganalisis bahagian intensiti tinggi imej kerana bahagian-bahagian ini mewakili suhu panas yang lebih tinggi. Seterusnya, bahagian ini akan dipangkas dan kualiti imej-imej ini akan dipertingkatkan dengan penyamaan histogram dan penyaring Weiner. Kemudian, perbandingan antara arus aliran elektrik dalam keadaan yang normal dan keadaan yang rosak akan dijalankan. Selepas perbandingan, system akan memberi amaran kepada pengguna jika terdapat kemungkinan rosak arus aliran elektrik. Kesimpulannya, teknik diagnosis automatic dapat mengurangkan tenaga manusia yang banyak, masa dan kesilapan manusia dalam diagnosis kerosakan elektrik.

MONITORING AND FAULT DIAGNOSIS OF ELECTRICAL INSTALLATION USING THERMAL IMAGING

ABSTRACT

Electrical fault is any abnormal electric current bypass the normal load. Thermal camera has been widely used for many years to monitor and inspect thermal defects of electrical equipment by detecting the hot-spot. However, manual analysis of infrared images for detecting defects and classifying the status of the equipment may consume a lot of time and efforts, and may also lead to incorrect diagnosis. In order to tackle this problem, image processing technique is introduced to analyze the possible electrical fault automatically from infrared images. In this project, Otsu’s method, Wiener filter and histogram equalization are implemented in analyzing the electrical fault. MATLAB is chosen as a platform to develop the algorithm to process the infrared image. In the first stage, the infrared images will be uploaded to the computer to analyze the high intensity parts of the image because these parts represent higher temperature hot-spot. Next, the hot-spot regions of the image will be cropped and the quality of these images will be enhanced by histogram equalization and Weiner filter. Then, comparison between the image of normal current condition and image of possible fault region will be carried out. After the comparison, it will alert the users if there is any possible fault. In this project, the ordinary Otsu’s method is modified so that it is suitable to be used to segment and analyse the electrical fault. If a fault is found on the system, a message will be generated by the system to alert the user. In conclusion, the automatic diagnosis technique can reduce a lot of manpower, time and prevent human error in electrical fault diagnosis.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

An electrical power system is a network of electrical components used to generate, supply, transmit and consume the electric power. It mainly composed of four sections which are generation, transmission, sub-transmission and distribution [1]. Each section consists of a lot of different complex dynamic and interacting elements, which are always prone to disturbance or an electrical fault [2].

The fault on electrical power system is an abnormal condition which mainly caused by the equipment failures, weather conditions, human errors and fires. Under normal operating conditions, the electrical equipment will carry normal voltages and currents. However, when the electrical fault occurs, it will cause short circuit and extremely high currents flows in the equipment. This will lead to the high temperature and damage the equipment or devices especially in the industrial and commercial area [3] [4]. This is because most of the operating system in this area required high voltage which is very dangerous if electrical fault is occurred. According to the research done by Richard Campbell [5] in 2017, the leading types of the equipment involved in the electrical failure or malfunction from 2010 to 2014 can be categorized into six main categories which shown in Figure 1.1. Among these six categories, electrical distribution, lighting, and power transfer accounted for the majority which was 57%. This means that most of the electrical failure or malfunction occurred in 3-phase electrical power system.

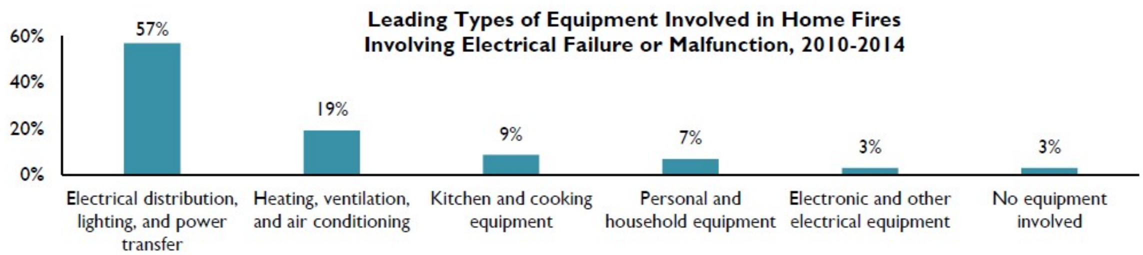


Figure 1.1 Leading types of equipment involved in electrical fault proposed in [5]

The traditional technique which is without IR camera [3] for analyzing and predicting the faults is also difficult and inaccurate. Besides, there are other factors which will affect the raising of the temperature in electrical power system such as absorption of the heat energy from the other sources [6]. This may affect the accuracy of the fault diagnosis. Hence, a proper and intelligent monitoring system should be developed to monitor the 3-phase electrical power system in order to prevent the effect caused by the electrical fault which needs to be cleared as fast as possible. Therefore, a good fault detection system is required to provide an effective, reliable, fast and secure way in the elimination of the electrical fault [2] [3].

For the monitoring system of the electrical fault, thermal imaging camera (TIC) [7] [8] is used to act as the eyes to monitor and capture the thermal image of the equipment. Although heat is invisible to our eyes but it can be detected by using thermal camera [9]. Thermal camera detects the temperature of the object which will emit the infrared radiation. The hotter the object, the more infrared radiation it produces. Besides, thermal images captured by using TIC can be in many forms such as grayscale image, rainbow color, RGB color, blue red color, and iron color. It consists of an array of heat sensors which detect the infrared radiation emitted by an object [10]. It is a device that forms an image using infrared radiation which is similar to the common camera that forms an image using visible light. Thermal camera provides fine-grained thermal information which can detect small temperature variations [11] [12].

In all thermographic electrical fault inspections, thermal image interpretation is performed by the human operator, which involves a high level of subjectivity and mainly relies on the expertise of the operator. In order to minimize the risk of the human error and reduce the waste of the manpower, an automation of the interpretation of the thermal images is proposed as a solution [13]. Therefore, an appropriate software is required as a platform to perform the algorithm for the electrical fault diagnosis. Matrix Laboratory (MATLAB) is chosen to process the thermal image taken by the thermal imaging camera in this project.

MATLAB is a programming language that is designed to perform numerical calculations with matrix based systems. It has a collection of built in mathematical supports such as diagonalization of matrix, optimization, and solving system of equations and differential equations [14]. Besides, it also contains a lot of tools which ease our work on algorithm. In this study, the thermal image captured by a thermal camera will be sent to a computer and undergo certain analysis. MATLAB will be used to develop and implement the algorithm to analyze the image by using the image processing technique. One of the techniques is by filtering and analyzing the red regions on the thermal image. This is because the red regions represent higher temperature which are the possible fault areas. Therefore, it is undeniable that the usage of automatic algorithms in appropriate software show to be valuable contribution for the electrical fault diagnosis [15].

1.2 Problem Statement

In the electrical power system, electrical fault is one of the dangerous situations which will cause severe damage to the property and also to the workers. Hence, proper preventive maintenance has to be carried out to make sure the equipment is well functioning. However, this will cause some issues such as time consuming, human error and waste of manpower [7] [13]. Shutting down all the power supply is required for the maintenance of the electrical equipment to be carried out. Recently, thermal camera is used to monitor and analyze the electrical fault. However, it still required manpower for operation. Therefore, a system with proper algorithm that can automatically analyze and detect electrical fault is highly desirable [13] [15]. This can help to reduce the time for fault diagnosis, manpower and also human error. Besides, the thermal camera only shows the thermal profile of the equipment and the high temperature areas [11] [12]. However, the increase in temperature caused by the increase in the current could be due to short circuit or increased load. Hence, this problem has to be considered during analysis of the electrical fault.

1.3 Research Objectives

The main objective of this project is to monitor and diagnose the electrical fault on electrical installation by using thermal imaging. The specific objectives are as follows:

a. To develop an image segmentation method to segment the electrical hot-spot from thermal images.
b. To analyze the segmented hot-spot and detect possible electrical fault.
c. To conduct experiment for analyzing different fault current and temperature profile.

1.4 Scope of Research

This project focuses on the electrical fault diagnosis on the 3-phase wires and equipment by using image processing technique on the thermal images. An experiment is conducted to analyze the different fault current and temperature profile by constructing a 3-phase circuit with different loads. The thermal image taken should be using the 'iron' color palette to ease the diagnosis process. Besides, the position of the thermal camera should be fixed when taking the thermal images of the electrical equipment. This is because the angle and position of the thermal camera will affect the quality of the thermal images taken which will lead to inaccurate result. Hence, the 3-phase wires should be located in front of a fixed thermal camera. This project implements the image processing algorithm using MATLAB which provides a lot of tools and function that simplify the implementation.

1.5 Thesis Outline

Chapter 1 consists of a brief background on electrical power system, electrical fault, thermal imaging camera and MATLAB. It also briefs about the problem statements, research objectives and scopes of research.

Chapter 2 presents a literature review of previous works related and the theoretical background. It describes the theory of the methods that to be implemented in this project. The electrical fault monitoring and diagnosis system on the 3-phase power system require high accuracy and simplicity method. Hence, a lot of image processing methods have been introduced and studied by researchers.

Chapter 3 presents the methodology of this research. It first describes the overview of the system works. Then, the chapter proceeds to describe the relation of the methods that used in this project to the electrical fault diagnosis such as contrast-limited adaptive histogram equalization (CLAHE) to improve the contrast of the thermal image, Wiener filter used to remove the noise of the thermal image and Otsu's method used to do the segmentation on the electrical fault.

Chapter 4 describes the results and discussion of this project. The findings of this project are presented in this chapter. The 3-phase fuses with or without wire loosen are segmented, compared and discussed. Besides, methods proposed in this project are also compared with the other methods. The findings of this project are illustrated in tables and figures.

Chapter 5 presents the conclusions of this project. This chapter shows the summary of the overall outcomes of this project and the future works that can be carried out to improve the system.

CHAPTER TWO

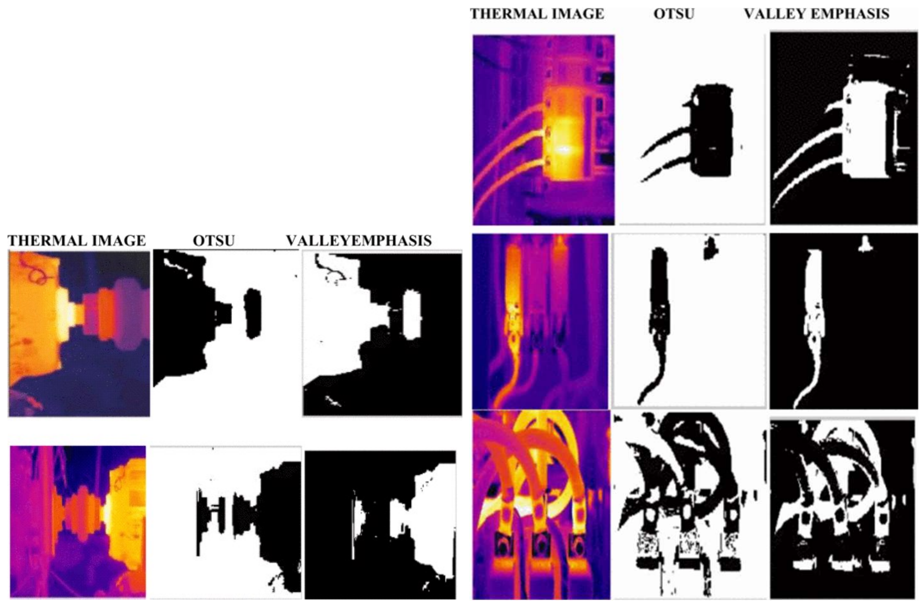
LITERATURE REVIEW

2.1 Overview

This chapter introduces the previous related work to this project and the theoretical background of the methods used in this project. Thermal monitoring and diagnosis system of the electrical fault can be used for monitoring any electrical equipment. It has been widely used at the power supply system, commercial and industrial area [16]. The traditional way to do the maintenance and fault diagnosis is to shut down the equipment [7]. This is time consuming and requires a lot of manpower. This may also result in human error [13]. During maintenance and fault diagnosis, it will cause inconvenience to the residents especially for the power plant and distribution substation. In order to prevent this from happening, non-contact automatic electrical fault monitoring and diagnosis system must be built to reduce time, manpower and eliminate human error [7]. This system diagnoses the electrical fault automatically by developing an automatic algorithm and alert the workers on possible electrical fault. Besides, high voltage and current are very dangerous which may lead to severe damage to the equipment and also workers. Hence, a system that can give early warning on electrical fault can prevent this from happening. In this project, three image processing methods will be investigated for automatic analysis of thermal images. They are histogram equalization used for contrast enhancement, Wiener filter used for image filtering and Otsu's method used for segmentation.

2.2 Related Works

Suguna, et al. [17] presented a method for fault localization of electrical equipment by using thermal imaging technique. In their research, valley-emphasis method was proposed to analyze the electrical fault. Otsu method was also used to compare with the valley emphasis. It was done for various electrical parts such as connectors and fuses. For the Otsu's thresholding technique, it is required to calculate all the possible threshold values and the pixel levels that fall in foreground and background. This is important to find the minimum threshold value for both foreground and background. For single thresholding, the pixels of an image are divided into two classes $C1 = \{0, 1, \ldots, t\}$ and $C2 = \{t+1, t+2, \ldots, L-1\}$, where t is the threshold value. These two classes are corresponding to the foreground and background. By using discriminant analysis, Otsu's method showed that the optimal thresholding, t can be determined by maximizing between class variance. Although Otsu method is good but it will fail to diagnose the fault if the histogram is unimodal. For valley emphasis method, the threshold value is to be selected with a small probability of occurrence which also maximizes between-class variance. The weighting term is inversely proportional to probability of occurrence and the optimal threshold is chosen by maximizing the revised objective function. The smaller the probability of occurrence will result in the larger weight. Weight is the only factor that determines the resulting threshold will be a value that resides at the valley or bottom rim of the gray level distribution. The results of the comparison between these two methods are shown in Figure 2.1. It can be concluded that the proposed model by M. Suguna, et al. [17] shows better segmentation of the hotspot region.



(a) (b)

Figure 2.1 Fault localization for (a) connectors (b) fuses proposed in [17]

Tamal Dutta, et al. [18] presented an electrical equipment monitoring system that uses thermal image processing. In their research, few methods were proposed to analyze the thermal image such as Hue, Saturation and Intensity (HSI) color model, edge based segmentation and Otsu threshold. HSI color model is created base on the RGB through some formula. Hue component describes the color in the form of angle from 0° to 360°. 0° means red, 120° means green and 240° means blue. Besides, the other colors can be obtained by adjusting the angle of the Hue. Saturation component describe the distance from axis while intensity component is the average of the RGB value of an image. Hue is meaningful when the saturation approaches to 1 and meaningless when the saturation approaches 0. It is the same goes to the intensity. For the edge based segmentation, Roberts, Prewitt, and Sobel operators were involved to calculate the gradient to find the hot region from the thermal images. Sobel operator compute the gradient that difference between rows and columns of the 3x3 neighborhood where the center pixel in each row or column is weighted by 2. Prewitt operator perform the partial derivatives by using convolution masks. The role components involved in the partial derivatives are intensities of the image neighborhood. Roberts operator compute the gradient that difference between rows and columns of the 2x2 neighborhood and its partial derivatives. For the Otsu threshold, it is used to automatically perform clustering based image threshold. The optimum threshold separating of the foreground and background images are calculated so that their intra-class variance is minimal. By performing these three techniques, the thermal images can be analyzed. In their research, this proposed method had tested on 27 standard thermal images and it gave better results as compared to standard grey scale technique. Figure 2.2 shows the result represented by T. Dutta, et al. [18].

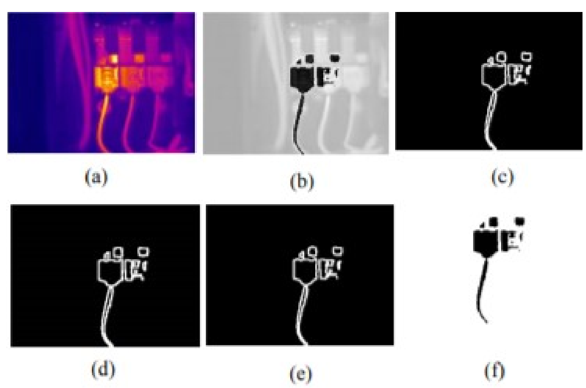


Figure 2.2 Result of HSI color model based image segmentation technique proposed in [18]

Surbhi Pareek, et al. [19] presented application of artificial neural networks to monitor thermal condition of electrical equipment. For the processing of the infrared image, greyscale images were used for analysis where pixels represent the intensity at that point. Light colored pixels show high intensity while dark colored pixels show low intensity. In other word, hotspot will carry light pixel. For the features extraction techniques used in their research were statistical features of order 1 based on histogram, grey level co-occurrence matrix (GLCM) features and temperature based statistical data as features. Statistical features of order based on the histogram of an image is about calculation of the Mean, Skewness, Variance, Entropy, Kurtosis, Standard Deviation and maximum values of intensity of the grey images. If mean is less than zero, mean intensity is greater than the pixel intensities of the whole grey image. GLCM consists of rows and columns that same number as grey intensities. It is used to calculate for the hotspots and reference image. In their research, GLCM was used to obtain the correlation, contrast, energy and homogeneity values as features. They used Fluke SmartView Software 3.0 to analyze the thermal image directly. The artificial neural network classifier they used is multilayer perceptron (MLP) feed-forward network. The architecture of the MLP network consists of 3 layers that are input, output and a central hidden layer. In MLP network all the neurons of all the layers are interconnected and these connections are weighted connections. In the present study, there were two algorithms used to train the MLP network which were Levenberg-Marquardt back-propagation (LM) and Scaled Conjugate Gradient (SCG). The optimal architecture of the MLP network can be reached by increasing the number of neurons from 1 to 50. For these two methods, LM algorithm converges faster than the SCG algorithm but SCG algorithm has higher accuracy as compare to that of the LM algorithm. The performances of the MLP network were shown in the Table 2.1. In a nut shell, this proposed method will save a lot time and more useful in large scale industries or plants where a large number of equipment have to be tested and analyzed together.

Table 2.1 Performance of MLP Network proposed in [19]

Input to the network	Training Algorithm	Training	Testing	Validation	Overall
Histogram and GLCM based features	SCG	77.8%	75.5%	73.5%	76.8%
	LM	77%	67.3%	73.5%	75.3%
Statistical data of temperature matrices	SCG	93.5%	89.8%	83.7%	91.5%
	LM	90.9%	87.8%	87.8%	89.9%

Redon, et al. [20] presented a reliable methodology for online fault diagnosis in induction motors using passive infrared thermography. In their research, infrared thermography and signal processing algorithms were proposed to analyze the fault. It was used to analyze two common fault conditions of induction motor which were bearing and ventilation system. For determining thermal sensitive regions, ThermaCAM Researcher software was used. After the thermal sensitive regions were identified, Fast Fourier (FFT) and Continuous Wavelet (CWT) transforms were applied by using standard toolboxes in MATLAB to do the time derivative of their temperature evolution. This method based on signal processing and it was importance to perform qualitative and quantitative analyses in active thermography (ACT) through analysis of vibration and current signals. FFT helped to convert the signal from time domain to frequency domain. This was importance to identify possible hidden patterns which were not visible in the time domain. Then, calculation of the power spectral density (PSD) at each frequency by using Welch method was carried out. Besides, CWT helped to contextualize in time domain the influence of those frequencies with a better temporal and spectral resolution than the short-time fourier transform. This allow the length of the wavelet function to vary by matching the spectral components of the signal and this feature was very important because the transient state was being considered in the healthy, bearing and ventilation fault scenarios. By comparing the ventilation fault and healthy scenarios as shown in Figure 2.3, some minor differences were observed. Higher power was observed for the healthy scenario in the first 200s which means that there was no forced convection. For ventilation fault scenario, higher power was in the range between 400s and 900s which means that the motor was heated up due to lack of forced convection. In a nut shell, these method techniques had inherent drawbacks such as need of qualified personnel for interpretation of their results but it was cost effective methods.

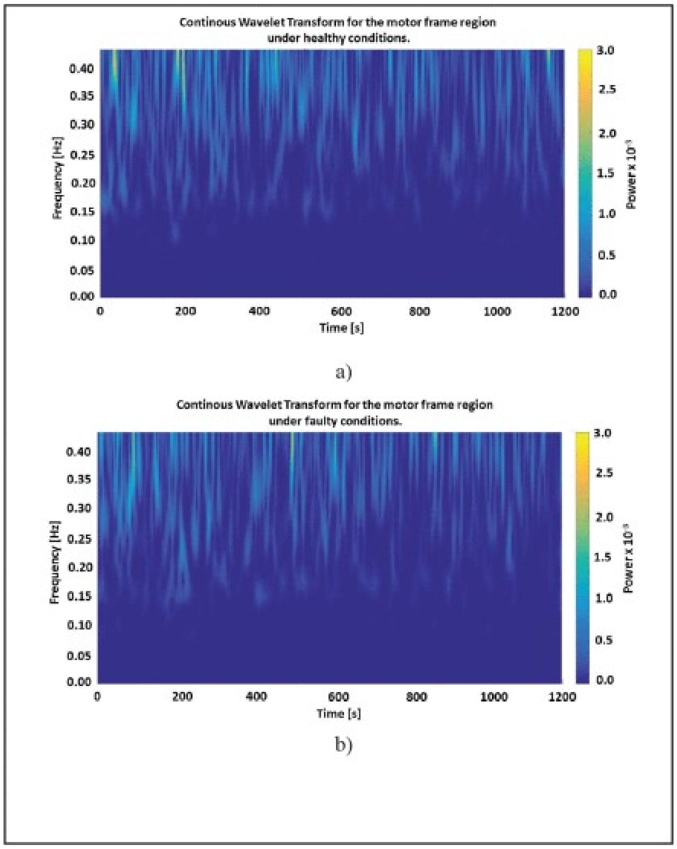


Figure 2.3 CWT results of ventilation fault and healthy scenario proposed in [20]

Ali Md. Younus, et al. [21] introduced a new method of machine fault diagnosis by using different machine conditions data such as normal, misalignment, mass-unbalance and bearing fault from infrared thermography (IRT). The information of the thermal image can be obtained by using image processing such as discrete Fourier transformation, discrete cosine transformation, neural networks, wavelet transform and others. In their research, discrete wavelet transform (DWT) was used to analyze the machine condition because of the complexity of thermal image data that was not conventional vibration signal data. Wavelet transforms are a forms of time-frequency representation for continuous time signals but it also can be discrete wavelet transformation (DWT) if in image signal analysis. Discrete wavelet transform (DWT) is a very recent mathematical tool of two-dimensional data handling. The wavelet coefficients are calculated to create the data. If scales and positions are powers of 2, positions are chosen to allow more efficient and accurate analysis. From decomposition fundamental, low frequency and high frequency content signal will be generated when the original signal passed through high pass and low pass filter. The decomposition algorithm starts with signals which is n by m dimensions to calculate the coordinates of approximation, horizontal detail, vertical detail and diagonal detail. Then, all the data is collected and decomposition level of coefficients plays an important role in the machine fault diagnosis. The algorithm of DWT is shown in the Figure 2.4.

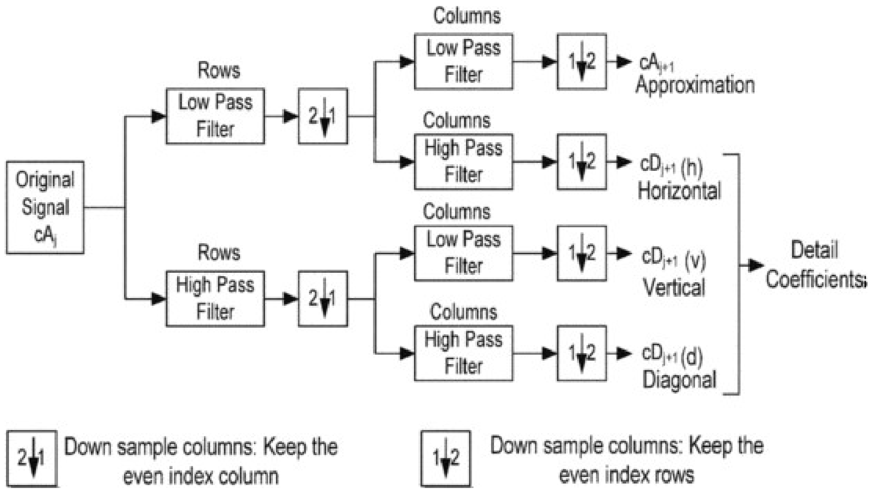


Figure 2.4 Algorithm of DWT proposed in [21]

In their research, the level N and type of wavelets were being selected and then the coefficients of the thermal image signal were determined by 2D DWT. In the decomposition of thermal image data from different condition machines, Bio-orthogonal wavelets of degree 3.5 and decomposition level of 3 were selected. After processed, four kinds of wavelet coefficients (A, HD, DD, VD) had found from each class of machine conditions data. However, approximation coefficients that pass through the low pass filter was considered for feature extraction because it contained most important part of original signal. In the feature extraction, standard deviation, mean, entropy, skew, kurtosis, and mean absolute deviation were extract from the four machine conditions. In the conclusion, the image analysis was to extract the information useful for application based problem. Bio-orthogonal wavelet algorithm had been successfully used to obtain the real machine conditions.

2.3 Theoretical Background

Image processing is a technique to enhance raw images and analyze the images using various methods such as image acquisition, image enhancement, image segmentation, feature extraction, and image classification. As a supplementary method in diagnostics, it can be used both statically and with dynamic temperature changes [22]. Besides, image processing can improve pictorial information for human interpretation and processing of image data for storage, transmission, and representation for machine perception [4]. Hence, it is widely used in many fields. In this project, image processing technique is used to analyze the thermal images and some methods are explained below.

2.3.1 Histogram Modification

Histogram play an importance role in the image enhancement. It reflects the characteristics of image. By modifying the histogram, the image characteristics can be modified. There are many methods related to histogram modification such as histogram stretching and histogram equalization.

2.3.1.1 Histogram Equalization

Among different image enhancement methods, histogram equalization is one of the most popular methods. This is because of its intuitive implementation quality, high efficiency, and monotonicity of its intensity mapping function [23]. This method spreads the histogram of pixel values to become more evenly. It is a nonlinear stretch that redistributes pixel values so that the number of pixels with each value within a range will be approximately the same [24]. In more complicated cases, global histogram may not be a good representation for local statistics in two parts of image. Hence, adaptive histogram equalization is used to divide the image into several rectangular domains, compute an equalizing histogram and modify levels so that they match across boundaries.

By considering discrete grayscale image A = {$a(x,y)$}, with a size of $H \times M$ pixels, where $0 \le a(x, y) < K$. K is the total number of intensities, H is height and M is width. Assume that the number of occurrences of an intensity k is equal to n_k. Then, the probability of an occurrence of a pixel of intensity k [23] in the image is

$$p_a(k) = \frac{n_k}{n}, \tag{1}$$

where n is the total number of pixels in the image A, $0 \le k < 1$. Besides, $P_a(k)$ also assumed to be the cumulative distribution function (CDF) corresponding to the histogram of image A.

In histogram equalization, highest quality images contain highest possible amount of information which mean that the images have a linearized CDF across the dynamic range. By creating a transformation of the form $b = T(a)$ to produce new image B = {$b(x,y)$} as the output image. HE performed by choosing transformation T according to

$$\begin{aligned} T(k) &= \arg\min\left|P_b\big(T(k)\big) - P_a(k)\right| \\ &= P_b^{-1}\big(P_a(k)\big) \\ &= (K-1)P_a(k) \end{aligned} \tag{2}$$

where P_b represented CDF corresponding to the histogram of image B.

From equation (2), the increment in the output intensity versus a unit step up in input intensity $k - 1$, $0 < k < K$, is actually

$$\begin{aligned} \Delta T(k) &= T(k) - T(k-1) \\ &= (K-1)p_a(k) \end{aligned} \tag{3}$$

Equation (3) shows that the intensities of the image are increased after equalization and the contrast gain is proportional to the probability of the corresponding pixel intensity in the input. However, this will also increase the contrast of background noises that have large pixel populations. Besides, the traditional HE has indiscriminateness issue. In order to tackle this problem, X. Wu, et al. [23] presented a histogram equalization (HE) based method for image enhancement called contrast accumulated histogram equalization (CACHE). This method is to formulate the potential visual importance on the basis of multi-resolution and dark-pass filtered gradients in the image. In equation (1) above, it depends on only pixel population. However, CACHE method has reformulated the probability of intensity k in image A by modifying equation (1) to

$$p_a(k) = \frac{\sum x \sum y \Phi(x,y)\delta(a(x,y),k)}{\sum x \sum y \Phi(x,y)}, \tag{4}$$

where Φ is the spatially variant function which shows the potential visual importance of each pixel, δ is the Kronecker delta, and $p_a(k)$ is the potential visual importance of an intensity of image A. This equation ensures the increment of intensity is proportional to its expected importance. Under normal situation, the brighter scenes are visually less important. Hence, the potential visual importance of each pixel is formulated by using dark-pass filtered gradients. Assume that $q = (x,y)$ be the coordinates of a pixel and $N(q)$ a set of neighboring coordinates of q. At each level l, the dark-pass filtered gradients is computed by

$$\varphi_l(\mathrm{q}) = -\sum_{q' \in N(q)} \min(\frac{a_l(q) - a_l(q')}{K-1}), \tag{5}$$

where $a_l(q)$ represented pixel while $a_l(q^l)$ represented the pixel's neighbors.

Equation (5) shows the attenuation of the contribution of pixels in smooth regions to density estimation during the amplification of the spatial distinctive pixels. However, there will be a condition that this equation will be triggered which is the intensity of the pixel should be darker than its neighbor. It incorporates both the spatial distinctiveness prior and dark prior pixels. Besides, Φ can also be formulated into

$$\Phi(x,\ y) = (\prod_{L=1}^{L} max\ (U(\varphi l(x,\ y)),\ \varepsilon))^{1/L}, \tag{6}$$

where U is the up sampling operator with a factor 2^{l-1} and ε is a small positive number that is used to avoid negative gradients due to interpolation. This function allows the original image A and image B to be equalized have the same resolution as image A.

Besides, the dark pass filtered gradients can also be extended to bright pass filtered and regular gradients by replacing negative minimum with positive maximum. The experimental result from their research is shown in Figure 2.5. From the figure, it can be concluded that CACHE method gives better contrast enhancement as compared to other image enhancement methods.

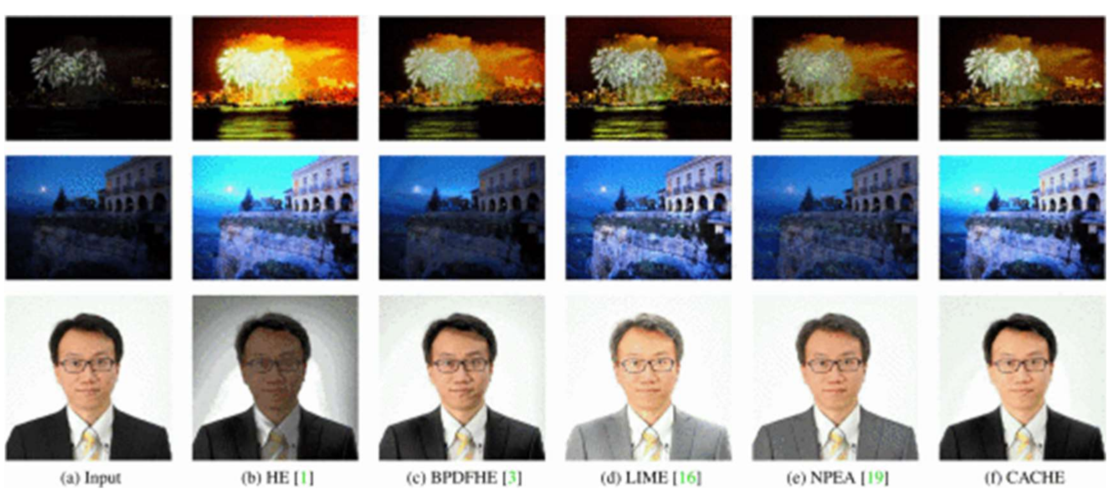


Figure 2.5 Comparison between CACHE and HE proposed in [23]

2.3.2 Image Filtration

Image filtration is an image processing technique used to suppress either high frequencies in the image or low frequencies in the image. It is used to smooth, enhance and detect the edges in the image. Normally, it is used to remove the noise so that the image looks nicer. There are a lot of type of image filtration techniques such as adaptive, Weiner, and Kalman filters [25]. In this project, Weiner filter is used to remove the noise after being processed by histogram equalization.

2.3.2.1 Wiener Filter

For Wiener filter [26] [27], it is a class of linear optimum discrete time filters which mainly focus on minimizing the function of error which is known as the cost function. It can be applied on many applications included image processing, signal processing, control system and digital communication. The objective of Wiener filter is designed to produce an estimate signal $d\hat{}(n)$ of the desired signal $d(n)$ using a linear combination of data $x(n)$. This process involved filtering, smoothing, predication and deconvolution.

To perform Weiner filtering, $x(n)$ and $d(n)$ should be assumed to have zero mean value and the filter coefficients should be maintained with time. Then, the output of the Wiener filter will be equal to the convolution of the input and the filter coefficient. The following shows the appropriate equations [25].

$$d^\wedge(n) = \sum_{m=0}^{M-1} W_m(n-m) = W^T x(n) \tag{7}$$

$$x(n) = [x(n), x(n-1) \dots \dots x(n-M+1)]^T \tag{8}$$

$$J = E\{(d(n) - d^\wedge(n))\} = E\{e^2(n)\} \tag{9}$$

where M is the number of filter coefficients, W is the filter weights, n is the number of input sample, T refers to transpose of the matrix, e(n) is error of current sample n, E is the expected value and J is minimum mean square of the difference between the actual output and desired one.

2.3.3 Image Segmentation

Image segmentation is a process of dividing an image into multiple parts and identify objects or other relevant information in digital images. There are many different ways to perform image segmentation such as Otsu's method, K-means clustering, watershed segmentation and texture filters. In this research, Otsu method will be explored for electrical fault segmentation from thermal images. Some explanations about the method is given in the following section.

2.3.3.1 Otsu's Method

In this study, Otsu's method is used to analyze the thermal image. Otsu's method is a thresholding techniques [28] where a threshold is selected either from the maximum of the between-class variance or the minimum of the within-class variance of the image histogram [29]. It can be used to segment out the objects that required further analysis from the background in the thermal image.

In the traditional Otsu's method, the intensity of the gray level image is expressed in L number of gray levels. Each gray level has specific number of points which denoted by x_i and the entire number of points can be expressed as $X = x_1+x_2+\ldots+x_L$. The histogram of this gray level image is defined as the occurrence distribution of probability [30],

$$p(i) = \frac{x_i}{x}, x_i \geq 0, \sum_{i=1}^{L} x_i = 1 \tag{7}$$

Besides, the pixels of the images can be divided into foreground and background parts. Foreground represents pixels within levels [1, 2, …, t] while background represents pixels within levels [t+1, …, L]. The occurrence probabilities of pixels of the images and its average can be expressed as respectively

$$\omega_0 = \omega(t) = \sum_{t=1}^{t} p(i), \tag{8}$$

$$\omega_1 = 1 - \omega(t) = \sum_{t=1+i}^{L} p(i), \tag{9}$$

$$u_0 = \sum_{t=1}^{t} \frac{p(i)}{\omega_0} = \frac{1}{\omega(t)} \sum_{i=1}^{i} i.p(i)\ , \tag{10}$$

$$u_1 = \sum_{t=1+i}^{t} \frac{p(i)}{\omega_1} = \frac{1}{1-\omega(t)} \sum_{i=1+i}^{L} i.p(i)\ , \tag{11}$$

$$u_T = \sum_{i=1}^{L} i.p(i) = \omega_0 u_0 + \omega_1 u_1, \tag{12}$$

$$\sigma_B^2 = \omega_0 (u_0 - u_T)^2 + \omega_1 (u_1 - u_T)^2, \tag{13}$$

$$n = max_{1 \leq t \leq L} \sigma_B^2, \tag{14}$$

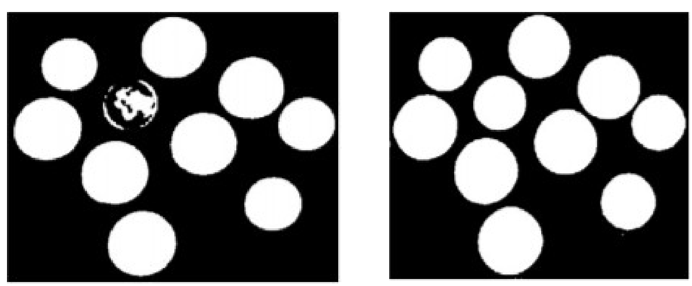
$$t^* = arg\, max_{1 \leq t \leq L}\, \sigma_B^2, \tag{15}$$

where ω_0 and ω_1 are the probabilities of foreground and background parts respectively. Besides, u_0, u_1 and u_T are the mean in gray levels of the foreground of the gray image, the background of the gray image, and the entire gray level image respectively. σ_B^2 is the between class variance of the foreground and background, n represents the separable degree of the class in discrimination analysis while t^* represents the optimal threshold.

However, the traditional Otsu's method has the weaknesses when used on the non-bimodal histogram of the gray level image. Hence, X. Yang, et al. [30] proposed a solution to improve the traditional Otsu's method. In their research, the distribution for the foreground and background can be skewed or heavy-tailed to allow the med-value to become very robust estimate value compared with the average gray level. By doing so, t^* obtained will become more accurate as compare to the traditional Otsu's method. Besides, total mean can be replaced with total median level of all points in the entire gray level image. Similarity, the means of foreground and background can also be replaced by median gray level, m_0 and m_1 respectively. m_T represented the image median value. The following equation shows the modified Otsu's method theory.

$$\sigma_B^2 = \omega_0(m_0 - m_T)^2 + \omega_1(m_1 - m_T)^2, \tag{16}$$

In their research, both original and modified Otsu method are implemented. From Figure 2.6, it shows that the modified Otsu method had achieve the optimal threshold which is better than the original Otsu method.



(a) (b)

Figure 2.6 Threshold result using (a) original Otsu method (b) modified Otsu method proposed in [30]

2.4 Summary

This chapter consists of two main parts. The first part describes the latest technology which implemented in the previous research. This technology is about the implementation of the image processing techniques on the high power system to diagnose the possible electrical fault. In part two, it describes the theoretical background of the image processing techniques used in this project such as histogram equalization, wiener filter and Otsu's method. The methodology to develop the proposed system in this project will be further discussed in Chapter 3.