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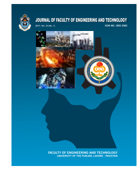

AUTOMATION IN FIELD OF THERMOGRAPHY OF ELECTRICAL SUBSTATIONS BY IMAGE PROCESSING TOOLS

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Abstract

In HV substations, thermal effects of temperature and resulting heating losses have a profound impact on the life of substation equipment. In order to efficiently detect these irregular heating patterns occurring in substation, a non-intrusive infrared thermography (IRT) based technique is suggested for detecting these abnormal heat variations in the electrical .substation equipment. In order to analyze thermal images of the substation, manual analysis may consume a lot of time and efforts and also there is every possibility of human errors in detection of faults. Thus to automate process of thermography, image processing techniques have to be opted for. In this paper, the process of image processing methodology consisting of feature vector extraction and image classification based algorithm are proposed here. Initially, two of the intelligent image processing techniques i.e. feature vector extraction techniques, K-means clustering and Fuzzy C-means (FCM) clustering, are proposed here and their results will be compared with each other with respect to their performance and efficiency. Then the substation equipment condition will be further evaluated and classified using Support Vector Machine (SVM) classifier to classify thermal images into two categories as normal or abnormal. The programming of the above mentioned techniques is done using MATLAB software. The proposed classifier technique results indicate higher accuracy above 90%.

Keywords: Thermographic; Region of Interest; K-means Clustering; Fuzzy C-means Clustering; Support Vector Machine.

1. Introduction

The HV electrical substations play a key role in disbursing and dispatching of electrical power efficiently and reliably to different areas. Their continuous and un-interrupting operation is of crucial importance for maintaining the power system reliability and availability. Thus the infrared thermography technique is used inspection of electrical substation. The purpose of inspecting the substation equipment is to make sure that all equipment is operating within their standard operation limits. The IRT measures the infra-red radiations coming out of the equipment. It is a well-known fact that any material operating at temperature of above absolute zero (0 Kelvin) emits heat energy radiations These IRT devices are designed and tuned to measure these infrared radiations to collect useful information. Thermography has emerged to be an excellent technique for monitoring and diagnosis of substation equipment. In order to make a correct and thorough diagnosis of substation equipment, a knowledge base of heating pattern and component identification must be developed [1].

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The IRT possess a lot of key advantages in context of equipment maintenance which are: more economical operation, less outages, decreased equipment downtime, better conservation of assets, improved safety pinpointing the fault location, reduced power losses in system [2]. Along with that the reduction in total duration of the outages ,the number of the outages as well as detection the quality of equipment and maintenance works can be determined [3]. Moreover, the useful life of equipment as per manufacturer's recommendations can be maintained and achieved [4]. During IRT inspection, most of the irregular heating is observed at the junction point or joints of equipment where clamps are bolted to connect the equipment and these are the much concerned problem areas in substation which can be detected and pinpointed at the exact location to find the hotspots [5].

Due to the nature of the connecting surfaces that are rough on micro scale to properly bond with the other connecting surface and because of small amount of roughness on the surfaces, their connecting area is small and any kind of corrosion, entrapped dust particles and oxidation in these contacts can cause the deterioration of the connection and result in excessive heating [6]. Two of the thermography measurement approaches are used in IRT inspection for condition monitoring and diagnosis of equipment in substation. Quantitative Approach [7], (ii) Qualitative Approach [8]. Two kinds of faults are detected during IRT monitoring process in the substation; (i)Faults of external nature, (ii) Faults of internal nature. The external faults are easier to detect because of outdoor nature but the internal faults are often masked by the equipment enclosures, cable insulations so these are difficult to explore [9].

In this paper, two of the intelligent feature extraction techniques, K-means clustering and Fuzzy C-means clustering, are employed as image processing methods to find accurately ROI of the target thermal images of substation equipment and then compared with each other with respect to their performance and efficiency. Then the features extracted from above techniques will be used to classify the images as 'Normal' or 'Abnormal' by using intelligent SVM classifier. The results of this image processing methodology demonstrate that it is accurate and robust. This will bring not early detection of incipient faults and diagnosis of the substation but also aid in repair and maintenance decisions of substation equipment.

Rest of the paper is arranged as follows: In the second section, the methodology of feature extraction techniques i.e. K means and Fuzzy C means and SVM classification technique is described. In the third section, results and analysis of the proposed techniques are discussed. In the fourth section, some of the challenges and future scope is detailed. In the final section, the paper is concluded with some remarks.

2. Image Processing Methodology

In this section, the steps for the image processing will be discussed along with the algorithms of the proposed feature extraction and classification techniques. The general theme of image processing is presented in Figure 1. These steps involved in image processing will be discussed one by one as we proceed towards image processing algorithms.

2.1. Infrared images

The first step in image processing is extraction of thermal images which are captured by some thermographic device. Here FLIR T440 thermographic camera is used for capturing thermal images. These are shown in two different palettes (grey and iron) bein Figure 2.

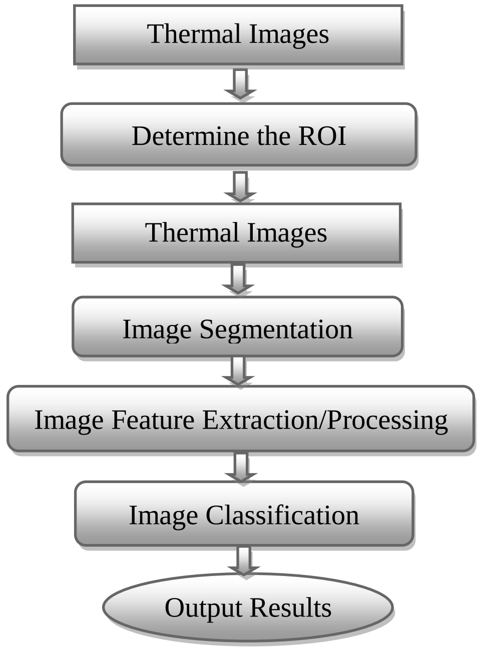


Figure 1. Image Processing Methodology Flow Diagram

2.2. Locating the region of interest (ROI)

To accurately locate region of interest (ROI) is the next stage in image processing methodology. Basically ROI is that subset of the image where the hotspots or faults of the substation equipment may lie which may indicate some aberration. Thus the exact location of region of interest is very important to further continue the process of fault detection by image processing. The ROI in thermal images of substation equipment is shown in Figure 3. The next step in fault detection of thermal images via image processing methodology is the segregation of the image from its background. As the extracted infrared image contains the intended thermal image along with its background, therefore the image must be segmented from its background. This process is also known as background subtraction or foreground detection. As the normally working equipment is heated above its surroundings or background, that portion of the image consists of high values of pixel intensities thus on that basis these high intensities can be filtered out from the dull background [12]. It is shown where thermal image is subtracted from its background is shown in Figure 4. The gray level images of thermal images are shown in the Figure 5 having distinction from its background.

2.3. Image segmentation

The next section in the image processing technique is the segmentation of the thermal image from the background. As the thermal image captured consists of the target image as well as the background the thermal image has to be initially segmented before the application of image processing technique. This technique is also called background subtraction or foreground detection. The target image contains high pixel intensity due to high temperature as compared to its surroundings; hence grey level histogram segments the image from its background [11]. An example of this is shown where thermal image having background is shown in Figure 4. The gray level images of thermal images are shown in Figure 5 having distinction from its background.

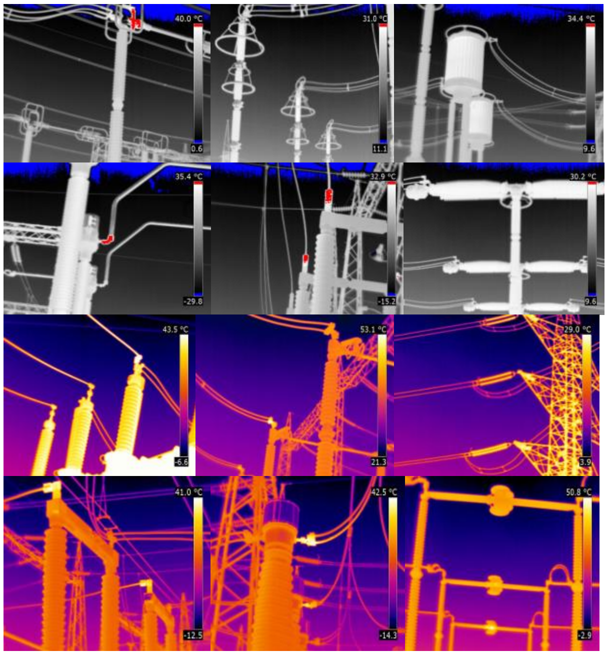


Figure 3. Thermal images of substation equipment

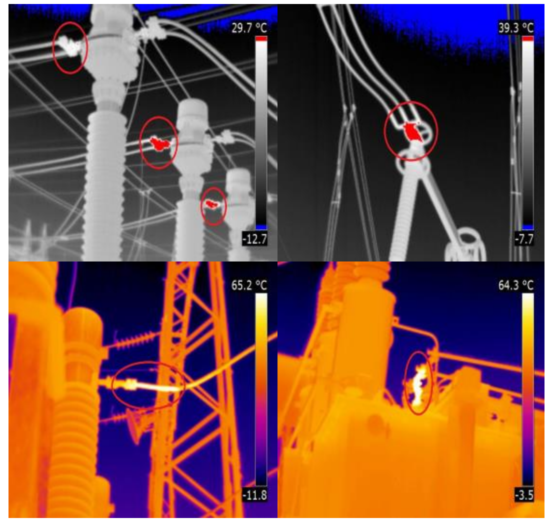


Figure 2. Region of interest (ROI) depicted in red zones of area

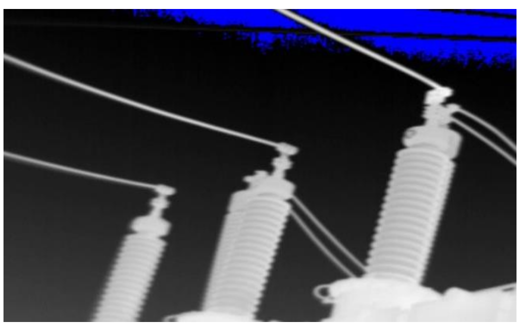


Figure 4. Original thermal image with background

Figure 5. Thermal image subtracted from its background

2.4. Image processing techniques

Firstly K means algorithm and Fuzzy c means algorithm will be explained and compared with each other. Then image classification technique SVM classification will be demonstrated.

2.4.1. K-means clustering algorithm

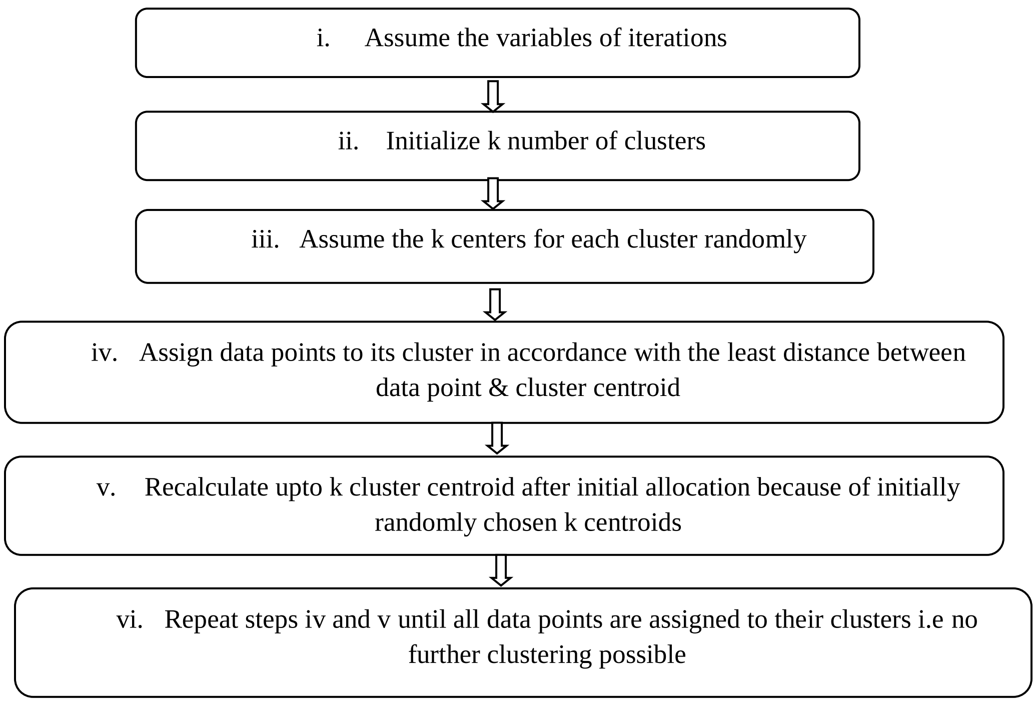
K means clustering, also known as Hard C means clustering, is basically a method in which a data point in a given dataset can only belong to one cluster. In this clustering process, the given dataset of n observations is portioned into k clusters. The k mean points are calculated for each cluster as k-centroids. The center point of each cluster represents the general characteristics of that cluster. It randomly chooses the centroid and then assigns the data points to the cluster by comparison of least distance with the centroid.

K means clustering iteratively keeps on updating the cluster centers upto k times until no improvements in updating centroids and movement of data points in corresponding clusters can be made. Finally this process segments the data points to their respective clusters. The objective function of K means clustering is shown in equation 1 as:

$$F = \sum_{x=1}^{k} \sum_{y=1}^{n} \left\| Xy - Cx \right\|^{2} \qquad (1)$$

Where $\left\| Xy - Cx \right\|^{2}$ is distance between data point X_y and the centroid C_x. The process of K means clustering [13] is depicted in steps in Algorithm-I:

Algorithm-I



2.4.2. Fuzzy C means Clustering

In this clustering process, the data points can be allocated to more than one cluster. It is known as soft clustering technique. The objective function FCM clustering intends to assign membership grading or degree of belonging to each data point in a given dataset instead of discreetly allocating to one cluster only. This grading membership is high if that particular data point lies in close proximity to the cluster centroid and on the other hand, the degree of belonging is low if the location of data point is at edge of the cluster. The objective function which Fuzzy C means attempts to minimize is given in below equation 2 as:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^{m} \left\| X_i - C_j \right\|^{2} \qquad (2)$$

Where the subscript m represents the level of fuzziness and has a value greater than one. **N** is the total number of data points, *C* is clusters in a dataset; u_{ij} is the degree of belonging of x_i to the cluster *j*. The FCM methodology [14] is given in Algorithm-II.

Algorithm-II

i. Initialize the number of Clusters & randomly choose a cluster centroid

⇩

ii. Initialize U= $\{u_{ij}\}$ matrix, $U^{(0)}$.Calculate the u_{ij} using:

$$u_{ij} = \frac{1}{\sum_{k=1}^{C}\left(\frac{\left\|x_i - c_j\right\|}{\left\|x_i - c_k\right\|}\right)^{\frac{2}{m-1}}}$$

⇩

iii. Calculate the centre vectors $C^{(k)}=\{C_j\}$ with $U^{(k)}$ at k^{th} step.

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^{m} . x_i}{\sum_{i=1}^{N} u_{ij}^{m}}$$

⇩

iv. Update $U^{(k)}$, $U^{(k+1)}$ after each iteration

$$u_{ij} = \frac{1}{\sum_{k=1}^{C}\left(\frac{\left\|x_i - c_j\right\|}{\left\|x_i - c_k\right\|}\right)^{\frac{2}{m-1}}}$$

⇩

If $\| U^{(k+1)} - U^{(k)}\| < \varepsilon$ or the minimum objective function J given in equation 2 is achieved, then STOP; otherwise return to step ii.

2.5. Image classification

The last stage of image processing methodology is the image classification. It is imperative to classify the images based on their characteristics. Normally Images are classified into two prevalent classes: (1) Normal images (2) Abnormal images. Here, an excellent image classification technique namely support vector machine (SVM) has been utilized to categorize the images into two classes. The support vector machine (SVM) is a supervised learning algorithm which is initially trained by a training dataset to make it able to learn and then the built supervised model response is tested and its accuracy is verified by applying test dataset.

The support vector machine (SVM) algorithm represents the dataset as special vectors in space and categorizes dataset into discrete classes. The goal of SVM is to find maximum possible the margin between the different classes to be identified in a dataset. Different steps involved in SVM classification process [15] are given in Algorithm-III.

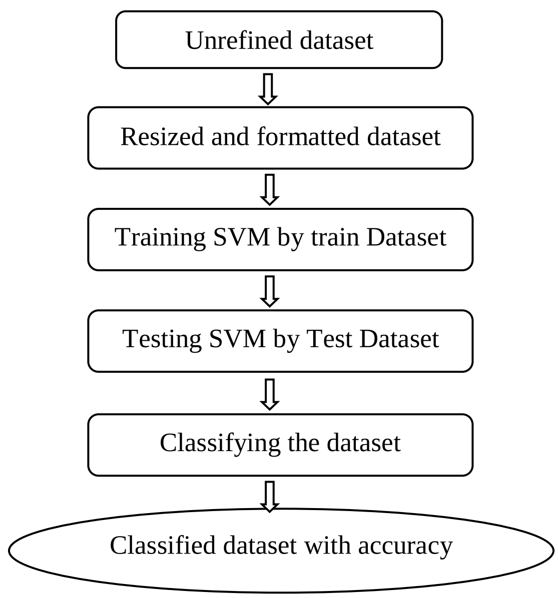
3. Results and Analysis

In this section, firstly proposed feature extraction techniques results will be analyzed and compared with each other with respect to their performance and efficiency (execution time) for processing thermal images of substation. The SVM algorithm results will be computed to out the find accuracy of proposed classification technique.

3.1. Results and Comarison of K means and Fuzzy C means

A high heated actual thermal image of 220kV circuit breaker captured by thermographic camera is shown in Figure 6 on which K means and Fuzzy C means clustering techniques will be applied. The results of K means clustering having 4 clusters are given below in Figure 7. As it can be seen from Figure.7 that from cluster no.1 to cluster no.4, the image is segmented with respect to high pixel intensities with ultimately fourth cluster identifies the maximum pixel intensity in the image i.e. actual fault in the target image.

Algorithm-III



The temperature of thermal image of hotspots is greater than its non-current carrying parts of equipment by a large margin so it has been categorized as the hotspot. The area of the hotspot shows that the severity of the region. Larger the area, more severe is the hotspot and vice versa. Thus K means clustering finds the hottest region in the thermal image. The results of FCM clustering having clusters are given below in Figure 8. As result of FCM shown in Figure 8 indicates the presence of hotspot. Thus, like K means clustering, this technique also works out to find hotspots present in the target thermal images.

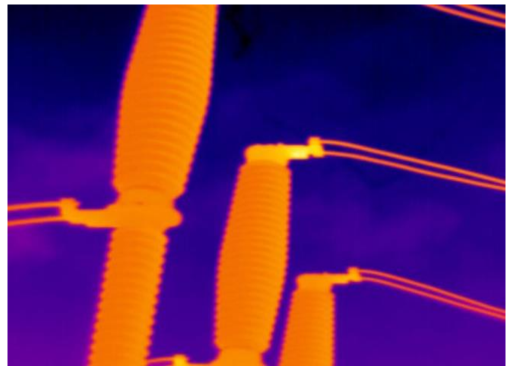


Figure 6. Thermal image of 220kV circuit breaker having hotspot

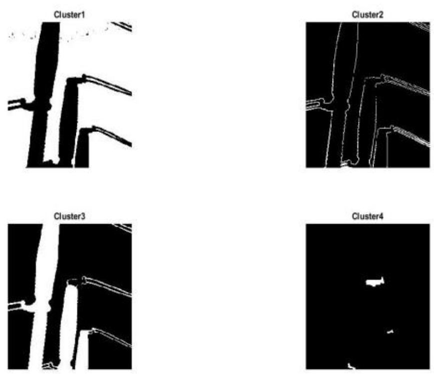


Figure 7. Clustered image of **220kV** circuit breaker

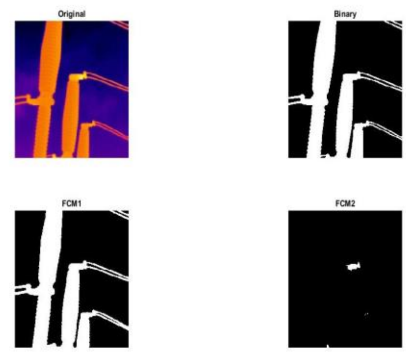


Figure 8. Thermal image of C.B along with its clustered images

3.2. Comparison of K means and Fuzzy C means clustering

The results may be observed from above clustered images from clustering techniques as shown in Figure 7 and Figure 8. The comparison between these two clustering techniques can be made with respect to two parameters i.e. efficiency (execution time) and performance (filtering).

i. Performance

As can be seen from the results of these two techniques, their results are somewhat similar. The objective functions of both these clustering techniques tend to reach global minima for a data having variable ranges of data i.e. variable temperature ranges.

ii. Efficiency

The result of these techniques with respect to efficiency or execution time is given elow in table 1.

Table 1: K-means clustering and FCM clustering efficiency

Sr. No.	Clustering Employed	Time Execution
1	K-means	6
2	FCM	20

3.3. Results and analysis of Support Vector Machine

As already mentioned that SVM is a supervised learning process so the algorithm has to initially trains itself by the training dataset which initially trains the classifiers and then tested by applying the test image dataset. The complexity and structure of data determines the total execution time required to process the dataset. The thermal images of substation are complex set of data so generally some time is required for the algorithm to train and test the whole data. In this research, thirty (30) images are used to train SVM. The classifier is initially trained for fifteen (10) normal images are then fifteen (abnormal) images and after that thirty (30) test images are used to check the response of SVM. The results of the algorithm are shown in table 2: It is clear from above results that the accuracy SVM classifier is around 93.3% which is excellent keeping in view the complex thermal images of substation. The execution time of the algorithm, while training a dataset of thirty (30) images and testing a dataset of thirty (30) images is around 140 seconds which is also good while processing thermal images.

Table 2: Results of SVM classifier method

Tested Images	**Correct Detection**	**Wrong Detection**	**Correct Detection (%)**
30	28	02	93.3

4. Conclusion

The IRT has been one of the excellent diagnostic techniques for on line inspection and condition monitoring. By adding advantages of image processing tools has reinvigorated the inspection process as it induces automation in the field of thermography thus preventing the very likely induced human errors as well as other error readings present in the raw thermal images. The image processing tools, used in this paper are K means clustering and Fuzzy C means clustering, that not only help in exactly locating the faulty section in the thermal images but can pace the fault detection process. Then, a comparison has been made between these two clustering processes from perspective of their resulting performance of segmenting the images; both these processes almost have similar results. After comparing the time execution of these clustering methods, K means shows superiority than FCM due to lesser time required for execution.

In order to classify the images, proposed process here is Support Vector Machine (SVM). This technique has been selected because of its simple algorithm and its ability to achieve higher accuracy even with the fewer amounts of available dataset to learn and train the classifier. The SVM classifier classifies the images into normal or abnormal depending upon its learning ability. The classification by SVM resulted in high accuracy of above 90% for detection of normal and abnormal images. The execution time required to process thermal images and classify is also less as compared to the other classification techniques so it is a great at promptly discovering problems in the substation equipment.

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