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A semi-automatic approach for thermographic inspection of electrical installations within buildings

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ABSTRACT

Maintaining the reliability of electrical installation has become part of the energy efficiency practices in building. The degradation of electrical installations can cause overheating, which can lead to subsequent failure of the equipments that can potentially result in unplanned power outages, possible injury and fire hazard. In addition, the efficiency of an electrical system becomes low prior to failure, thus energy is spent generating heat and causing unnecessary energy loses. Therefore, early prevention is required to avoid this situation by monitoring the reliability of the electrical installations through energy audit practices. This article proposes a semi-automatic approach for evaluating the thermal condition of electrical installations within the building in Malaysia by analyzing its infrared image. Initially the interest regions of the images are manually segmented. Then the statistical features of first order histogram and gray level co-occurrence matrix features as well as the differences of feature parameters between hot and reference regions are extracted from segmented regions. Principle component analysis is applied for the best features selection and at the final stage, the condition of electrical equipments will be classified using multilayered perceptron neural network. The performances of multilayered perceptron networks have been compared and tested with various training algorithms. The classification accuracy of multilayered perceptron networks are also compared with discriminant analysis classifier and it is found that the multilayered perceptron network using Levenberg–Marquardt algorithm gives the best testing performance. The result shows that the maximum testing accuracy 78.5% was obtained.

1. Introduction

According to the latest report [1] of Fire and Rescue Department of Malaysia about the causes of fire in buildings, 2317 fire related incidents have occurred between January 2012 and June 2012, making the average number of incidents around 387 a month. In this report, 1049 of fires were caused by electrical problems which was about 46% of the total causes of fire in building and were mainly involved the electrical wiring problems (809 cases) and failure of electrical equipments (240 cases). Failure in electrical distribution equipments can potentially produce an ignition and fire. One of the causes of ignition is excessive ohmic heating in electrical distribution [2]. This condition can occur especially for old buildings with outdated electrical wiring that is deteriorating, inappropriately amended, or insufficient for the electrical loads. However, new constructions also are not protected from this condition. If the quality of the connection degrades, in effect, more energy will dissipate from the devices as its electrical resistance increases [3]. Therefore, periodical monitoring and diagnosis of equipments condition are essential for early fault detection and maintaining the energy efficiency in buildings.

Infrared thermography (IRT) is the best and useful tool to monitor and determine the heat related problems [4–8]. Various problems can also be detected within the monitoring such as poor connections, short-circuits, overloads, load imbalances, and improperly installed electrical components [9]. The system allows on-line maintenance process without interruption of service, minimizes downtime, reduces outage and manpower cost, avoids sudden failure of the equipments that could be catastrophic, injuring and losing of life [10–12].

Applying automatic condition monitoring system can improve the fault detection technique and the level of abnormalities in electrical equipments can be evaluated even when the expert or experienced personnel are not present [13,14]. For instance, Almeida et al. proposed an intelligent faults diagnosis system based on thermography for surge arrestors using two kinds of variables as inputs of neuro-fuzzy network [15]. This system was designed to classify faults into two classes which are normal or faulty and the index of wrong classification result is found to be lower than 10%. Shafi'i and Hamzah used RGB colour scale data and temperature

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Table 1
Classification of conditions of electrical equipments.

Priority	Type of condition	ΔT between similar components (°C)	Recommended action
1	Critical	$\Delta T \geq 15$	Major discrepancy; repair immediately
2	Warning	$5 < \Delta T < 15$	Indicates probable deficiency; repair as time permits
3	Normal	$\Delta T \leq 5$	Minor overheating; warrants investigation

data as the input features of artificial neural network to detect faults in electrical equipments [16]. Rahmani et al. developed an intelligent system to detect faults of electrical equipments in ground substations using support vector machine (SVM) as a classifier and 22 image features of Zernike moments [17].

In this research work, an automatic classification system for determining the conditions of electrical equipments was implemented. Initially the infrared images of electrical equipments were manually segmented into two different region of interest (ROI) for the same load and condition. One of the ROI is the suspected faulty component while the other one is the normal component which is usually assigned as the reference component. Most of the electrical equipments and components are installed side by side; therefore it is easy to segment all the components with the same size. Asymmetry analysis of these two ROIs is found to be the appropriate way to analyse the conditions of the equipments. Two kinds of statistical based feature extraction methods namely histogram based first order statistical and second order grey level co-occurrence matrix (GLCM) statistical texture analysis method are widely used to describe the asymmetry between these two regions [18]. Seven orders of the first order statistical approach and four orders of the GLCM texture analysis method were used. Total 22 features are extracted for both reference and hot component as a separate parameter namely reference and hot parameter respectively.

Suitable feature selection is an important task for ensuring better performance of classifier especially in high building. Because, some input features are highly uncorrelated or irrelevant those can decrease the classifier performance and this can cause incorrect analysis of energy editing process. For reducing the features, various feature selection methods such as principle component analysis (PCA), and discriminant analysis (DA) can be used. In this article, PCA [19] is used to select the suitable features for condition monitoring of equipments. It is found that PCA is the simplest, easy to apply and provide true eigenvector based multivariate analysis tool. At the final stage, multilayered perceptron (MLP) neural networks are used for classifying the conditions of electrical equipments which were divided into 3 classes i.e. normal, warning and critical. The performance of MLP networks were compared using twelve different training algorithms namely Levenberg–Marquardt (LM), Broyden–Fletcher–Goldfarb–Shanno quasi-Newton (BFG), resilient back propagation (RP), scaled conjugate gradient (SCG), conjugate gradient with Powell-Beale restarts (CGB), Conjugate gradient with Fletcher-Reeves updates (CGF), conjugate gradient with Polak-Ribiere updates (CGP), One step secant (OSS), Bayesian regularisation (BR), Gradient descent (GD), Gradient descent with momentum and adaptive learning rate (GDX) and Gradient descent with momentum (GDM) algorithm. Details of these algorithms can be found in [20]. The performances of classification are evaluated based on overall percentage accuracy. Performance of MLP neural network is also compared with discriminant analysis classifier.

2. Infrared image acquisition and manual classification approach

Infrared images of electrical equipments are captured from main switch boards (MSB) from different locations of old office buildings and factories. Fluke Ti25 thermal camera with fusion technology was used to capture the images. The thermal imager consisted of a 160×120 focal plane array, uncooled microbolometer detector and operated in the infrared spectral band of 7.5–14 μm. The thermal lens capture images of 320×240 pixels while the ordinary lens produced 640×480 pixels (visual images). All the infrared images of electrical equipments were collected at the main switchboard which is supplying the electricity to an office building. For capturing the image, the thermal imager orientation is directly facing to the target electrical equipment in order to get an accurate measurement. The distance between the target electrical equipment and the thermal imager is in the range of 0.5–1.0 m. Emissivity measures how well the surface emits energy. In this study, the thermal picture of electrical equipments was captured from main switch boards in buildings. The metal surface of equipments was painted or oxidized and also some of them were covered by high-quality electrical tape. The standard emissivity of most organic materials and painted or oxidized surfaces is 0.95 [21]. Most low voltage and many medium voltage switchgear and components have high emissivity materials near the connection points. From molded case breakers to cable insulation, an emissivity of 0.95 should perform better [22]. It was noted that the ambient temperature around the equipments is between 30 and 33 °C during the inspection. A total of 500 infrared images with different electrical equipments were captured.

Conventionally, the condition of electrical equipment is evaluated by comparing the temperature value between abnormal (hot) and reference (normal) components. This technique is known as qualitative measurement which is analysed by measuring the temperature difference, ΔT between normal and abnormal components. Usually, the temperature of normal (reference) component is assigned as minimum temperature and the temperature of abnormal (hot) component is assigned as maximum temperature. *Several standards for measuring* ΔT are found such as InterNational Electrical Testing Association (NETA) [23], American Society for Testing & Materials (ASTM) – E [24] and National Fire Protection Association (NFPA) – NFPA 70-B [25]. In the present study, based on the experience from inspections results, the conditions of equipments are classified instead of using the available standards. For an accurate temperature measurement, some important parameters related to environmental effect, target equipment conditions as well as the technique used for capturing the image have to be considered [26].

In this research, the conditions of equipments are classified into three classes which was normal, warning and critical condition. This specification is illustrated in Table 1 with their corresponding recommended audit actions. Based on our survey on 500 electrical equipments 125 equipments are classified as critical, 193 equipments as warning and 182 equipments as normal condition. This results show that 25% of the equipment had to be repair immediately and 38% indicate probable deficiency. A huge saving of energy is expected if the equipments are being replaced immediately. For example, thermal insulation survey of a 460 MW thermal power station with four units in India shows that about 1.02 million kcal/h energy losses was occurring due to bare surfaces, inadequate/damaged insulation or open cladding condition in all four units. Further analysis shows that if these faulty insulated areas are attended there would be energy saving of around 0.774 million kcal/h [27]. All these equipments were evaluated manually using infrared image analysis software. Some examples of the conditions are depicted in Fig. 1, where the abnormal condition is clearly shown by the red colour.