DEFECT DETECTION AND PREVENTIVE MAINTENANCE PRIORITIZATION OF DISTRIBUTION CUBICLES BY INFRARED STATISTICAL IMAGE PROCESSING

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ABSTRACT

Major defects in distribution cubicles create hot spots which can be detected by infra-red cameras. Preventive maintenance teams use infra-red images for finding defects in distribution cubicles, because these defects can lead to electricity distribution interruption, fire accident and damage of other part of cubicle. Infra-red image analysis, which is called Thermovision, is one of the main branches of machine vision. Although thermovision has been being used for finding defects in electrical components, related infrared images are inspected only by empirical methods and few researchers who work on infra-red image processing have not used control charts for this purpose. Variety of components and configurations, lack of training data, high serial dependency and complex behaviour of thermal conductivity are challenging matter which should be overcome when a proper method is developed. Image monitoring, which was used in current research, is based on finding change in images by spatial control charts. Spatial control chart is a special control chart which is used for finding abnormality in image. In this research combination of spatial control chart and robust regression was used for defect detection in infrared images and its ability for this purpose was evaluated.

INTRODUCTION

Deteriorated or loose connections, improperly-installed or mismatched components, short circuits, overloads and load imbalance are main sources of hot spots in distribution cubicles which can interrupt energy delivery to customers, increase the risk of fire accident and cause other components damage. Therefore, maintaining the proper condition of cubicles is very important for distribution companies. There are thousands of distribution cubicles in provincial network and it is not possible to overhaul all of them immediately. Preventive maintenance teams find defects in cubicles by infra-red cameras and repair them according to defects severity and other priorities. Although Infra-red cameras have been being used for inspection and finding defects in electrical components, quality control tools have not been widely used for enhancing empirical methods. Consequently, the severity estimation level of hot spots depends on thermographer personal perception which may not be reproducible.

Traditional image processing tools like support vector machine or artificial neural network need sufficient training data, but there is not enough thermogram for training these models. Therefore, developing a method which needs only data of each image for analysing is necessary.

Alborz province power distribution company have started a pilot project for cubicles preventive maintenance prioritization. This paper introduced the statistical method developed and used in the pilot project for finding defects in infra-red image of electrical components. Although it is not possible to enter the details of the statistical theories which have been used in this research in four page paper, we tried to explain the fundamental concept of image monitoring.

STATISTICAL PROCESS CONTROL AND SPATIAL CONTROL CHART

Statistical process control (SPC) is an approach of quality control which uses statistical tools like control charts for process variability monitoring. Although SPC is focused on industrial application, this approach has assisted numerous researchers in monitoring non-industrial data.

Control charts are statistical tools which are used to distinguish between variation produced by insignificant random causes and assignable causes. Control charts present a graphic display of process stability. Basic control chart, which is called Shewhart control chart, consists of points representing statistic, upper and lower control limits and center line. When statistic points are between upper and lower limits, the process is assumed under control, but if points exceed control limits the process is out of control. In Shewhart control chart, the state of process control depends only on the last measurement of process. Uniformly weighted moving average control chart, or simply moving average control chart, is an extension of basic control chart using ‘n’ most recent measurements instead of only last one. EWMA (exponentially weighted moving average) control chart is another useful control chart which its statistic is exponentially weighted average of all prior data, including the most recent measurement. By selecting proper weight factor, which is called lambda, EWMA control chart can be sensitive to gradual drift in process. Mathematical and practical texts about control charts can be found in Montgomery [1] and Oakland [2] books.

Image monitoring, monitoring image by control charts, has been used in increasing number of applications [3]. Many application of image monitoring is base on spatial control chart. Spatial control chart is a special control chart which its horizontal axis represents a position in the image. Spatial control chart has a window moving across the image and uses statistical data of relevant part of image for monitoring variation in the image [3].

A few researchers applied spatial control charts for monitoring image data. Jiang et al used EWMA control charts for detect the type, size and location of the defects in LCD monitors [4]. Lu and Tsai applied machine vision and spatial X-bar chart for detecting defects in LCD panels [5]. Finally, Lin and Chiu developed a method for detecting lighting variation defects in LCD monitors by Hotelling T2 control chart [6]. Image monitoring is not confined to LCD defect detection. For example, Tun'ak et al used SPC for monitoring weaving density and plain weave defect detection in the direction of the fabric length [7]. Majority of other researchers like Colosimo [8] used non-spatial control chart for image monitoring.

Basic control chart construction is based on independence between individual data points, but when data are taken in order, there is a risk of serial dependence or autocorrelation. Basic control charts are vulnerable to autocorrelation and if autocorrelated data are plotted on standard control charts, there is usually a tendency for false alarm [2]. There are some remedial methods such as autoregressive models and EWMA control chart for reducing false alarm rate which is related to autocorrelation.

INFRARED IMAGE PROCCESSING

Only few researchers have worked on defect detection by infra-red image processing. To the best of our knowledge, the research of Almeida, who used Nero-fuzzy to find defects in high voltage lightning surge arresters thermogram [9], is the only similar study.

Thermograms of distribution cubicles possess the attributes which should be overcome in image processing:

I. Distribution cubicle components have been connected to each other with copper bars and wires. Copper is very good heat conductor so the heat produced in hot spots is transferred to other zones of cubicle by the thermal conductivity and radiation.

II. Heat increases electrical resistance which itself intensifies heat of components. Therefore, serious hot spots can exaggerate the severity of adjacent hot spot

III. Thermal isolating materials in cubicle like glass and plastic may cover hot components.

IV. Heat equation describing the distribution of temperature in a given region over time is partial differential equation. The solution of this equation is complex, even with simple boundary condition.

V. There are many regional maximums in 3D image but few of them are real hot spots that represent real defects.

VI. Different equipments have been installed in cubicles depending on installation time and manufacturers decision. In addition, Outdated or damaged components are replaced with new components with different shape and size.

VII. Some obstacles like adjacent trees, cars and municipal utilities prevent maintenance crew from taking thermal photos of cubicles in predefined distance and view angle.

VIII. Operators who are responsible for taking thermograms omit unnecessary part of cubicles. Therefore, position of suspected damaged components in thermogram depends on operators' perception.

The last three characteristics of distribution cubicle increase the diversity of thermogram. Therefore, there is not enough data for training models and it is necessary to develop methods depending only on statistical data of each image instead of traditional image processing tools like support vector machine (SVM) or artificial neural network which need a lot of training data.

Photo of two sample distribution cubicles and their thermogram have been displayed in figures 1 to 4.

Figure 1: Photo of cubicle 1

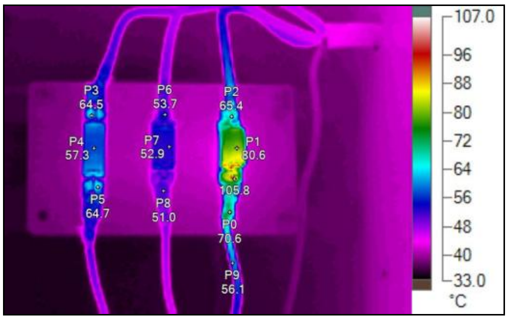

Figure 2: Thermogram of cubicle 1

Figure 3: Photo of cubicle 2

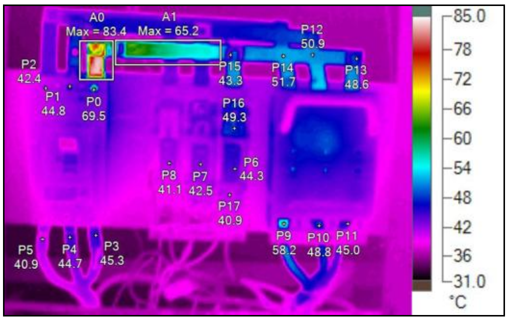

Figure 4: Thermogram of cubicle 2

METHODOLOGY

Edge detection is one of the traditional methods for finding objects in images. In this method, edges of objects are found and analyzed by some classification tools like artificial neural network. Although it is possible to find and hot spots in simpler thermogram like figure 2 by edge detection, in more complex thermogram which copper bars connect hot devices to each other like figure 4, thermal conductivity of these bars disrupt the edge detection. The alternative approach which is used in current study is image monitoring by spatial control chart. This control chart was generated by moving a window across the image. The window positions do not overlap and the size of it depends on the expected size of the hot spots [3].

High thermal conductivity of copper bars and wires can interference with simple moving window result. Furthermore, the positive dependency of observation in adjacent pixel can lead to false alarm in control charts. Therefore, the movement of scan window should be modified. In suggested method, which includes two stages, whole thermogram has been divided into small square parts with same size. In first stage, all parts in each row are combined horizontally and scan window moves vertically across thermogram. The hot spot should be found in the bands related to out of control point. In second stage, scan window moves on these bands for locating the exact place of hot spot. Result of image monitoring of a sample thermogram was plotted in figure 5.

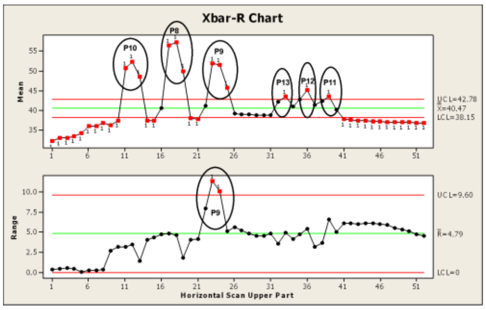

Figure 5: Shewhart control chart of thermogram (hot spots was marked by ‘p…’)

For reducing the effect of autocorrelation, many methods have been developed, but a few of them are suitable for spatial control charts. The simplest approach is using EWMA. This method can be effective if autocorrelation is positive and data average is not changing rapidly [1]. Forecasting models can be used for eliminate observation autocorrelation too. In this approach autoregressive model was fitted to observation data and its residuals are plotted in control chart [1]. Least squares regression model is a well-known model for forecasting but prediction can be distorted if residuals, the differences between observations and the values predicted by the model, are very large. These residuals are called outliers. Hot spots related to major defects are much hotter than their adjacent components and like other outliers can distort the regression. Robust regression can limit the influence of outliers and provide resistant results in the presence of them. In robust regression, the sum of squared errors is replaced with one less influenced by outliers. M-estimation introduced by Huber is an approach that can reduce the impact of outliers with reasonable computation [10].

Even though complex boundary conditions and heterogeneity of low voltage cubicle have made it impossible to use the heat transfer partial differential equation directly for developing forecasting model, it is possible to estimate it by linear function, which can be estimated by regression.

$$T_i = \sum_{i=1}^{n} \beta_i (T_{i-1} + T_{i+1}) + \varepsilon_i \text{ Or } T = \tau' B \qquad (1)$$

The general M-Estimator introduced by Huber minimizes the following objective function [12]:

$$\sum_{i=1}^{n} \rho(\hat{T}_i - \tau' B) \qquad (2)$$

Bisquare objective function, which has been selected in this study, is defined as below:

$$\rho_B(e) = \begin{cases} \frac{k^2}{6}\left(1 - \left(1 - \left(\frac{e}{k}\right)^2\right)^3\right) & |e| \le k \\ \frac{k^2}{6} & |e| > k \end{cases} \qquad (3)$$

In this study, individuals and Moving Range (I-MR) chart have been modified for eliminating false alarms and increasing control chart sensitivity.

DISTRIBUTION CUBICLES MAINTENANCE PRIORITIZATION

For distribution cubicle maintenance prioritization, it is necessary to evaluate the hot spot severity. NETA guideline has been selected for this purpose. In this guideline the difference between components and ambient temperature is used for estimating the level of defect severity. According to NETA if temperature difference is more than 40°C immediate action is necessary [11].

Table 1: Thermal specification of hot spot severity according to NETA standard [11]

Priority	Delta T over ambient	Recommended action
4	1°C to 10°C	Possible deficiency; warrants investigation
3	11°C to 20°C	Indicates probable deficiency; repair as time permits
2	21°C to 40°C	Monitor until corrective measures can be accomplished
1	> 40°C	Major discrepancy; repair immediately

RESULT AND DISCUSSION

For comparing hot spot detection ability and false alarm rate of different control charts, eight different thermograms of old cubicle had been selected for hot spot detection. All thermograms related to various installed cubicles in Shahrequds territory in Tehran province .Before image processing, thermograms had been analyzed and their hot spots had been clustered by expert engineers. The result of analysis showed that there were 419 regional peaks in 8 thermograms but only 17 of them related to real defects.

Different kinds of spatial control chart including IM-R, EWMA (λ=0.05, λ=0.2 and λ=0.8), Xbar-R, Xbar-S, moving average (n=3 and n=10) and have been used for analysis of all thermograms. All spatial control charts with three different size scan windows have been plotted. After analyses, number of errors have been counted and depicted in figures 6 and 7.

The result of image monitoring showed that:

I- Defects in simple thermograms was found by most spatial control charts with proper scan window, but defect in complex thermogram only could be found by forecasting residual IM-R control chart with proper scan window.

II- If scan window was larger than necessary, some defects would be lost, but using small window increased the rate of false alarms.

III- Xbar-S and Xbar-R control charts were very susceptible to autocorrelation, especially when small scan window was used.

IV- Changing λ in EWMA control chart had great effect on finding defects. Using EWMA control charts with large λ like 0.8 many leads to false alarms, especially when scan window was small. On the other hand, if smaller λ like 0.05 was used, false alarms number would be reduced but some defects would be lost.

CONCLUSION

Spatial control charts can find abnormality in image without training data and this advantage help researchers to analyze some unique and complex images. In current project we used this advantage for finding defects in distribution cubicles.

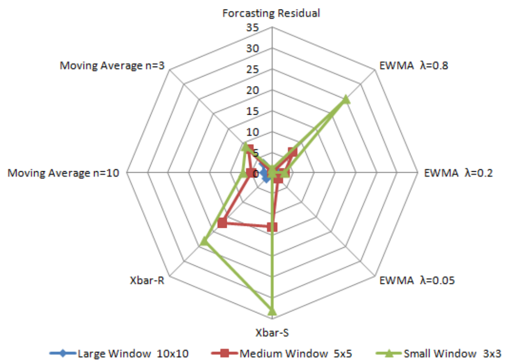

Figure 6: Number of False alarm

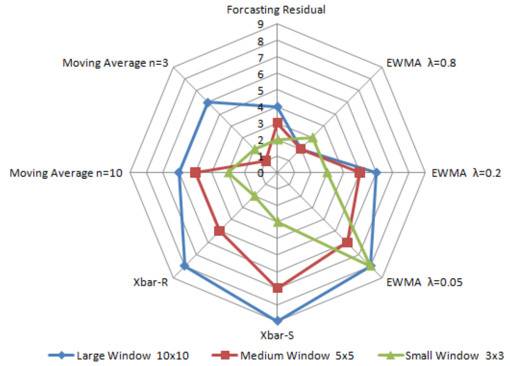

Figure 7: Number of not-detected hot spot

Although determining scan window size is a challenging topic in spatial control chart, we hope that systematic method for solving this problem will be introduced.

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