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Detecting defective electrical components in heterogeneous infra-red images by spatial control charts

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ABSTRACT

Distribution network components connect machines and other loads to electrical sources. If resistance or current of any component is more than specified range, its temperature may exceed the operational limit which can cause major problems. Therefore, these defects should be found and eliminated according to their severity. Although infra-red cameras have been used for inspection of electrical components, maintenance prioritization of distribution cubicles is mostly based on personal perception and lack of training data prevents engineers from developing image processing methods. New research on the spatial control chart encouraged us to use statistical approaches instead of the pattern recognition for the image processing. In the present study, a new scanning pattern which can tolerate heavy autocorrelation among adjacent pixels within infra-red image was developed and for the first time combination of kernel smoothing, spatial control charts and local robust regression were used for finding defects within heterogeneous infra-red images of old distribution cubicles. This method does not need training data and this advantage is crucially important when the training data is not available.
Aims: Developing a new method to detect defective electrical components in the power distribution cubicles.
Place and duration of study: Tehran province, Iran, 2011–2013.
Methodology: Combination of kernel smoothing, spatial control charts and local robust regression used for finding defects within heterogeneous infra-red image of old distribution cubicles.
Results: This study showed that the IM-R control chart that plots forecasting residual of local robust regression and EWMA control chart with proper λ parameter with proper scan window size are powerful control charts which can be used to finding defected components in the power distribution cubicles.
Conclusion: In some applications like analyzing thermal images of the old power distribution cubicles, it is not possible to train a sophisticated model like artificial neural network to identified defects. Therefore, spatial control chart that does not need training data is a valuable tool for these applications.

1. Introduction

Statistical process control (SPC) is a set of tools like control charts developed for improving process capability by quality monitoring and process variability reduction. Image monitoring, which is an extension of profile monitoring, has been used in the increasing number of applications. In these applications, image data is monitored by control charts. Spatial control chart has a window moving across the image and statistical data of relevant part of image is plotted. Horizontal axis of spatial control chart represents a position in the image [1].

A few researchers have applied spatial control charts for monitoring image data. Jiang et al have introduced a method for checking uniformity in LCD monitors. They have used analysis of variance (ANOVA) for identifying areas significantly different from other areas in a panel and exponentially weighted moving average (EWMA) control charts to detect the type, size, and location of the related defects [2]. Lu and Tsai have used machine vision and spatial X-bar control chart for detecting defects in LCD panels [3]. Lin and Chiu have utilized Hotelling T2 control chart to detect lighting variation defects in LCD monitors [3]. Tun'ak et al. have applied SPC for detecting plain weave fabric defect and monitoring weaving density in the direction of the fabric length [4]. Majority of other researchers like Armingol et al. [5] and Colosimo et al. [6,7], have used non-spatial control chart for finding defects. Although most

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of the past research efforts have been focused on either detecting variation among many images or within an image, in a paper published in 2012, Megahed et al. have introduced spatiotemporal framework which monitors both the spatial and the temporal aspects of image data [8]. Previous research findings corroborate that spatial control charts are powerful tools for finding defects in images and it is possible to enhance detection ability of spatial control chart with other tools such as principal component analysis [1].

Image data is not confined to visible spectrum. Thermovision is a branch of the machine vision focused on analyzing thermograms, the thermal map of an area of interest generated by an infra-red camera. Due to the fact that electrical current produces heat, very high temperature areas are seen when current or media resistance is higher than specified range. These high temperature areas are called hot spots. Therefore, it is possible to find defective electrical components by analyzing thermograms. Although thermovision has been being used to inspect electrical components for finding defects, quality control tools such as control charts, have not been used to enhance the empirical methods and control charts has not been applied to thermal image yet by the researchers who are interested in the infra-red image processing field. For example, Almeida et al have used Nero-fuzzy method to find defects in high voltage lightning surge arresters thermograms [9]. Other researcher have introduced many methods for inspecting thermal images of wind turbine blades [10], high-voltage contacts condition [11,12], power transformer [13], molded case circuit breakers [14] and some other power components [15,16].

There are thousands of switches, connectors, distribution cubicles and other components in provincial electrical network and distribution companies have focused on cost-effective maintenance strategies. Reliability centered maintenance (RCM) is a valuable approach for defining safe minimum levels of maintenance which can increase profitability of distribution companies by addressing dominant causes of distribution network failure. Distribution cubicles, which are used in both industries and power distribution network, not only connect industrial machines and other power consumers to electrical source but also contain electronic devices to control and protect network and equipments. Deteriorated or loose connections, improperly installed or mismatched components, short circuits, overloads and load imbalances are the main sources of defects in the cubicles. Defects in the distribution cubicles can reduce reliability, damage machines, increase the risk of fire incident and interrupt production. Therefore, condition of the cubicles is crucially important for power distribution companies. Preventive maintenance teams of these companies should detect the defective components in the cubicles before they cause electricity supply interruption. Variety of components and configuration, high serial dependency and complex behavior of thermal conductivity should be considered when a method is used to finding defects in thermograms of distribution cubicles. In addition, it is necessary to develop methods only based on statistical data of each image because there is not enough data for training traditional image processing tools like support vector machine (SVM) or artificial neural network.

Current research presented in this paper is rather unique because of its conceptual differences from the already published researches in the following areas: Firstly, most of previous researches were based on the assumption that either uniformity or special patterns exist in images, but thermograms of installed electrical components are not only heterogeneous but also without repeating pattern. Therefore, it is not possible to use simple a standardization methods like subtracting a standard image from the captured image. Secondly, "in control" images are not normally available and lastly, control charts are normally utilized for production quality control but in current research were used for Reliability Centered Maintenance (RCM) prioritization. Distribution cubicles have the most complicated thermograms. Therefore, this paper was focused on finding defects in them but proposed method can be applied to simpler thermograms like junctions and switches.

In the present study after describing the characteristics of the distribution cubicles thermogram, a new scanning pattern method which can tolerate heavy autocorrelation has been presented and for the first time, thermograms have been analyzed by spatial control charts. Different methods such as local robust regression models and EWMA for minimizing serial dependency of thermogram image data have been evaluated. Finally, hot spot detection ability, number of false alarms and lost hot spots, of different methods has been compared.

2. Problem description

Low voltage power distribution cubicles, which contain low voltage control and protection devices, are very important components of electrical distribution network. There are thousands of these cubicles in provincial distribution networks and Industries. Thermogram, which represents temperature distribution of objects, can be used to identify defects in distribution cubicles. Preventive maintenance engineering teams who are responsible for maintenance planning of the cubicles use visual inspection reports and thermograms to find the defective parts and to determine the severity of defects. NETA is one of the practical guidelines which is used for conducting infra-red inspections of electrical systems and rotating equipments. Severe hot spots that have priority one in NETA should be eliminated as soon as possible [17].

Low voltage cubicles are characterized with the following features that make their thermogram analysis rather complicated:

(I) The heat produced in hot spots can be transferred elsewhere due to thermal conductivity and radiation. Equipments in a low voltage cubicle are connected to each other with copper bars and wires which are very good heat conductors. Heat increases electrical resistance which itself intensifies heating of adjacent components. In addition, thermal isolating material in the cubicle may cover hot components. Therefore, shape, size and maximum temperature of a hot spot is affected by other components and configuration of the cubicles.

(II) The equations explaining the behavior of thermal distribution in a cubicle are complex. Heat equation, describing the distribution of temperature in a given region over time, is a partial differential equation. By Fourier's law, the flow rate of heat energy through a surface is proportional to the negative temperature gradient across the surface, where k is the thermal conductivity and T is the temperature.

$$q = -k\nabla T \tag{1}$$

Change in thermal energy per unit volume of material (ΔQ) is proportional to the change in temperature (ΔT), where ρ is the mass density of the material and c_p is the specific heat capacity.

$$\Delta Q = c_p \rho \Delta T \tag{2}$$

Heat Equation leads to the Sturm–Liouville problem that can be solved by partial differential techniques. Its analytical solution is usually a complex mixture of trigonometric and exponential functions depending on boundary and initial conditions.

(III) In urban and rural distribution networks, obstacles like adjacent trees, vehicles and municipal utilities and in industries other parts of machinery prevent maintenance crew from taking thermograms of cubicles in predefined distance and view angle.