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Infrared Image Enhancement and Segmentation for Extracting the Thermal Anomalies in Electrical Equipment

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Introduction

In recent years, infrared imaging has become an important tool particularly for predicting and preventing electrical equipment's failure [1]. It can reveal various types of problems in electrical equipment by sensing the emission of infrared energy (i.e. temperature) of the equipment. It is well understood that the life of electrical equipments is drastically reduced as temperature increases. Condition monitoring using infrared images has the capability to detect and evaluate the presence of any anomalies in the thermal distribution profile, produced by the defect on the surface of the equipment. The defect will normally alter the thermal signature of the surface due to the change in the amount of heat generated and the heat transfer properties of the equipment.

Infrared imaging inspection is well known as a non-contact measurement technique where the inspection can be done without interrupting or shutting down the operation of a system. It offers many advantages over conventional temperature measurement technique, including the capability of fast response times, wide temperature ranges, two-dimensional data acquisition, high spatial resolution, safe, reliable and very cost-effective approach for an electrical power system maintenance program [2].

However, the nature of an infrared image is quite different from that of visual light image. The formation of a thermal image is purely based on the heat distribution of an object. It brings some difficulties to image segmentation due to its over-centralized intensity distribution and low intensity contrast [3]. Furthermore, extracting the hot region within an infrared image has become a challenging task, especially when the image contains a very complex background and low signal-to-noise ratio (SNR) [4]. Another reason of producing the low-quality images such as blurring effect, low target-to-background contrast and noises in infrared images is due to the limitation of infrared camera technology availability [5].

Therefore, in order to improve the performance of image segmentation, this paper proposes a method for enhancing the warm regions in infrared image of electrical equipment while at the same time reducing the effect of unwanted background. The warm regions then can be detected by using thresholding segmentation technique. The remainder of this paper is organized as follows: the next section briefly introduces various segmentation techniques and followed by the proposed enhancement method for improving the visibility of the warm regions. Afterward, the segmentation results and their performance analyses are presented and discussed. Conclusion appears in the last section.

Image segmentation

Image segmentation is one of the challenging tasks in image analysis. The purpose of segmentation is to subdivide an image into its constituent regions or objects. Thresholding technique has been widely used in various image segmentations because of its simplicity and easy to implement [6]. While numerous segmentation approaches for automatic threshold determination have been proposed over the past several years, applying new ideas and concepts to image thresholding remains an interesting and challenging research area [7].

In examining the thermal condition of electrical equipment, thresholding technique is a very useful method for separating the warm region from its background. The possible thermal anomalies in the equipment can be detected by filtering the image using a certain threshold value. If the original image is *I(x,y)*, the thresholded image, *G(x,y)* is defined as

$$G(x,y)=\begin{cases}1 & if\ I(x,y)>T,\\ 0 & if\ I(x,y)\le T,\end{cases} \quad (1)$$

where T is the threshold value. The segmentation result is in the binary image form where 1 represents the target object or region and 0 represent for background image.

For an automatic finding of thresholding value, Otsu method [8] has been widely used in various applications. The optimum threshold value is obtained by determining the maximum between-class variance (BCV) of the foreground and background pixels. The optimum threshold value is given by

$$T_{opt} = \arg\max\left\{\frac{P(T)[1-P(T)][\mu_f(T)-\mu_b(T)]^2}{P(T)\sigma_f^2(T)+[1-P(T)]\sigma_b^2(T)}\right\}, \quad (2)$$

where μ_b and μ_f represent the mean values of the image background and foreground, respectively. σ_b is the standard deviation for image background while σ_f is the standard deviation for image foreground. $P(T)$ represents the cumulative probability is defined as

$$P(T) = \sum_{i=0}^{T} p(i), \quad (3)$$

where

$$p(i) = \frac{n_i}{N}, \quad (4)$$

where $p(i)$ is the probability distribution of image histogram, n_i is the frequency of gray level i and N is the total number of pixels in the image.

In another approach of finding optimum threshold value, Kapur et al. [9] proposed a segmentation method by calculating entropy of the image histogram. The image is said to be optimally thresholded when sum of the entropies for object and background reaches its maximum. The threshold value is determined by

$$T = \arg\{\max_{1\le T\le L}(H_B(T)+H_F(T))\}, \quad (5)$$

where

$$H_B(T) = -\sum_{i=0}^{T}\frac{p(i)}{P(T)}\ln\left(\frac{p(i)}{P(T)}\right) \quad (6)$$

and

$$H_F(T) = -\sum_{i=T+1}^{L}\frac{p(i)}{P(T)}\ln\left(\frac{p(i)}{P(T)}\right). \quad (7)$$

where $H_B(T)$ and $H_F(T)$ are the image entropy for background and foreground respectively. L is the highest gray level contains in the image.

Kittler and Illingworth [10] presented an approach based on minimum error thresholding (MET) by optimizing the average pixel classification error rate. Among various methods in thresholding based segmentation technique, MET has been found the best-performing segmentation algorithm for both nondestructive testing (NDT) and document images [7]. Threshold value for MET is defined by

$$T = J_B - J_T, \quad (8)$$

where

$$J_B = 1 = 2(P_B(T)\log\sigma_B(T) + P_F(T)\log\sigma_F(T)) \quad (9)$$

and

$$J_T = 1 = 2(P_B(T)\log P_B(T) + P_F(T)\log P_F(T)), \quad (10)$$

where P_B and σ_B are probability distribution and standard deviation for background image while P_F and σ_F are probability distribution and standard deviation for foreground image.

Hamadani [11] determined the threshold value by employing first order statistical properties, in order to extract the warm regions in infrared image. The threshold value is determined by

$$T = k_1 \times \mu + k_2 \times \sigma, \quad (11)$$

where, μ represents the mean value of the image which is given by

$$\mu = \frac{1}{M\times N}\sum_{x=1}^{M}\sum_{y=1}^{N} I(x,y) \quad (12)$$

and standard deviation, σ of the image is calculated using

$$\sigma = \sqrt{\frac{1}{M\times N}\sum_{x=1}^{M}\sum_{y=1}^{N}(I(x,y)-\mu)^2}, \quad (13)$$

where k_1 and k_2 are the constants which should be determined manually. It is recommended that the value of k_1 and k_2 are equal to 1 for low resolution image. For higher resolution infrared image, the value of k_1 and k_2 are set at 1 and 1.5 respectively in order to produce a better segmentation result [12].

Fuzzy-C means (FCM) based segmentation was developed by Bezdek [13]. This method proposes a fuzzy membership which assigns a degree of membership for each class. FCM algorithm is an iterative optimization that minimizes the objective function, Q which can be defined as

$$Q = \sum_{i=1}^{n}\sum_{j=1}^{C}(u_{ij})^m \left\| v_i - \mu_j \right\|^2, \quad (14)$$

where n is the number of samples and C is the number of clusters. μ_j and v_i represent the center of the j–th cluster and the i–th measured data, respectively. m is the weighting exponent parameter that controls the fuzziness of the resulting partition whereby $m \ge 1$. The membership matrix, u_{ij} should satisfy the condition

$$\sum_{i=1}^{C} u_{ij} = 1, \forall j = 1,\ldots,n. \quad (15)$$

The memberships and the cluster centers are updated using the following relationships

$$u_{ij}^m = \frac{1}{\sum_{k=1}^{C}\left(\frac{\left\|v_i-\mu_j\right\|}{\left\|v_i-\mu_k\right\|}\right)^{\frac{2}{m-1}}}. \quad (16)$$

where

$$\mu_j = \frac{\sum_{i=1}^{n} u_{ij} \cdot v_i}{\sum_{i=1}^{n} u_{ij}}, \quad (17)$$

where k is the iteration number. By iteratively updating the cluster centers and the membership degrees for each data point, the FCM algorithm iteratively processes until either the maximum number of iterations is reached or the value of Q is optimally minimized.

Hot region detection

In an infrared image, the most important image information is usually the region of interest with bright or dim gray values. However, because of the effect of imaging environment, the region of interest may be blurred or the contrast between the regions of interest and surrounding regions is low, which result in a poor visual effect and may affect the quality of image segmentation.

Applying pixel intensity adjustment technique, the targeted region of interest can be enhanced and the surrounding background can be separated. In this method, the pixel intensities of an original infrared image of electrical equipment are inverted by subtracting the image with the highest pixel value. Therefore, the inverted image is

$$I_{inv}(x, y) = \max(I(x, y)) - I(x, y), \quad (18)$$

where $I_{inv}(x,y)$ and $I(x,y)$ are the inverted and original image, respectively. x and y are the pixel locations in the image where all the original images are in gray scale form.

In order to enhancing the warm regions and reduce the effect of unwanted background, the inverted image is then subtracted by the original image using

$$I_h(x, y) = I(x, y) - I_{inv}(x, y), \quad (19)$$

where $I_h(x,y)$ is the result of warm regions enhancement.

This technique will clearly adjust the visibility of the warm regions and at the same time minimizing the effect of background noises. By subtracting one image from another shows us the difference between the images' pixels. Fig. 1 shows the infrared image enhancement process of a circuit breaker. The inverted image (Fig. 1, c) changes the pixel intensities where the brighter regions will become darker and vice versa. The different between original (Fig. 1, a) and the inverted image can clearly enhance the warm regions contains in the image (Fig. 1, d).

Result and discussion

All the infrared images were captured using Fluke Ti25 thermal imager. The thermal imager consisted of a 160 X 120 focal plane array, uncooled microbolometer detector and operated in the infrared spectral band of 7.5 µm to 14 µm. The thermal lens capture images of 320 x 240 pixels while the ordinary lens produced 640 x 480 pixels (visual images).

The images were captured at the main switch board of office buildings in University Malaysia Pahang (UMP), Malaysia, during the electrical system running at high load demand. For capturing the image, the camera orientation is set directly facing to the target equipment in order to get an accurate measurement. All the captured images were saved in gray scale format (256 gray levels, 8 bit).

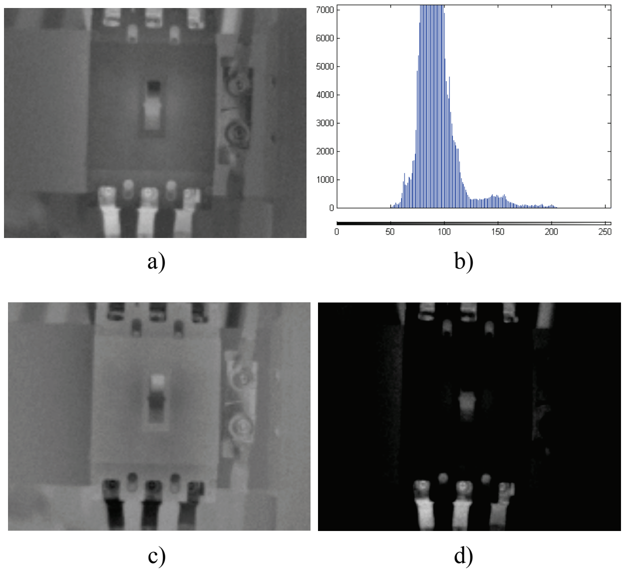


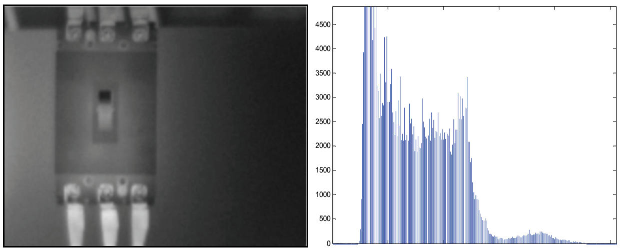
Fig. 1. Infrared image enhancement: a – original infrared image; b – image histogram; c – inverted image; d – result of image enhancement

The results for segmenting the original infrared image of electrical equipment based on the aforementioned methods are represented Fig. 2 with their respective thresholding values. Correct image segmentation is depending on how identical to the ground truth image (Fig. 2, c). It is clearly can be seen that, Hamadani (Fig. 2, e) and Kapur (Fig. 2, g) methods yield a better segmentation result compared to Otsu and MET methods. Here for Hamadani method, the value of k_1 and k_2 are set at 1.5 and 2, respectively.

MET thresholding method offers the worst segmentation result (Fig. 2, f) where the image is said to be over-segmented. Nonetheless, not all the tested images produce a bad segmentation result as the shown in the figure. Even so, over-segmentation is still a big issue for this method. Otsu method (Fig. 2, d) shows better result than MET with the threshold value at 79. The output result is still can be considered as over-segmented.

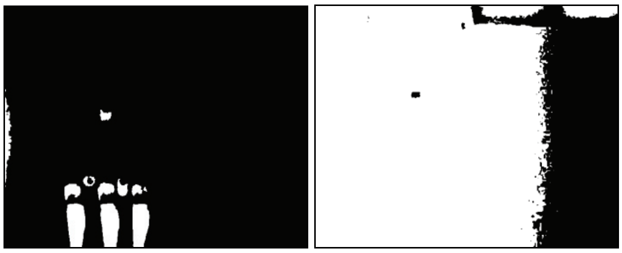
The same over-segmentation also happened to FCM method (Fig. 2, h) but slightly better than Otsu. The thresholding value for the image is 99. Here, the final segmentation result for FCM is gotten after 32 iterations with the objective function stopped at 1139.729627. For all tested images using FCM, the parameter m=2.

The result of image segmentation after implementing the proposed image enhancement is depicted in Fig. 3. As compared to the ground truth image (Fig. 3, c), Otsu (Fig. 3, d) and FCM (Fig. 3, h) show a very competitive result. Both methods yield the threshold values at 69 and 102 respectively. Obviously, Otsu thresholding method has shown a significant improvement compared to the previous segmentation using original infrared image. For FCM, the final segmentation is produced after 28 iteration and objective function at 199.567709.



a) b)

c) d)

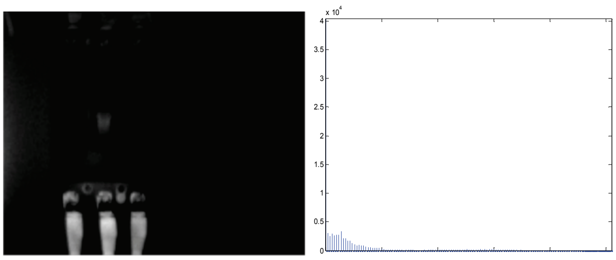


e) f)

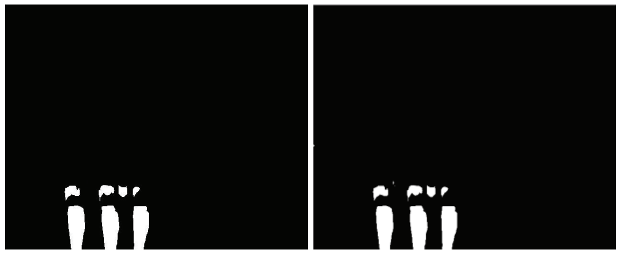
g) h)

Fig. 2. Segmentation result: a – original infrared image; b – image histogram; c – ground truth image; d – Otsu (T=79); e – Hamadani (T=136); f – MET (T=41); g – Kapur (T=138); h – FCM (T = 99)

However, there is not much different for Hamadani (Fig. 3, e) and Kapur (Fig. 3, g) methods even after applying image enhancement. Both methods yield threshold values at 49 and 50 correspondingly. On the other hand, MET method has shown some improvement in reducing the effect of over-segmentation.

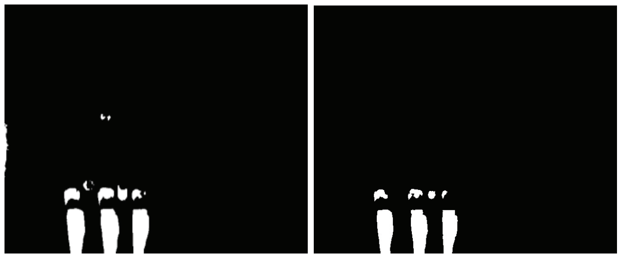


a) b)



c) d)

e) f)



g) h)

Fig. 3. Segmentation result after enhancement: a – infrared image after enhancement; b – image histogram; c – ground truth image; d – Otsu (T=69); e – Hamadani (T=49); f – MET (T=3); g – Kapur (T = 50); h – FCM (T = 102)

It is clearly can be observed that the image enhancement can provide some improvement on segmenting the warm regions in an infrared image. Direct segmentation from original image brings some difficulties for extracting the warms regions. To know the accuracy the image segmentation, quantitative evaluation should be carried out. The next section focuses on evaluating the segmentation performance for all the above mentioned methods.

Performance evaluation of image segmentation

The performances of image segmentation algorithms are evaluated for both original and enhanced images. In order to evaluate the accuracy, the output of image segmentation is compared to their corresponding ground truth (GT) images. The performance and the accuracy of the segmentation methods are evaluated based on parameters of true positive rate (TPR), false positive rate (FPR) [14], the Jaccard similarity index, Dice similarity (DS) index [15] and the absolute error ratio [16].

In order to determine all these indexes, parameters such as false positive (FP), false negative (FN), true positive (TP) and true negative (TN) should be calculated. This can be done by examining the overlapping between segmented images (SI) and GT, which can be illustrated as two sets as shown in Fig. 4. *TP* can be defined as the number of true positives where the image pixels of the foreground are correctly classified. *TN* is the number of true negatives by which the image pixels of the background are correctly classified. *FP* and *FN* are the number of false positives (pixels of the background classified as foreground) and the number of false negatives (pixels of the foreground classified as background), respectively.

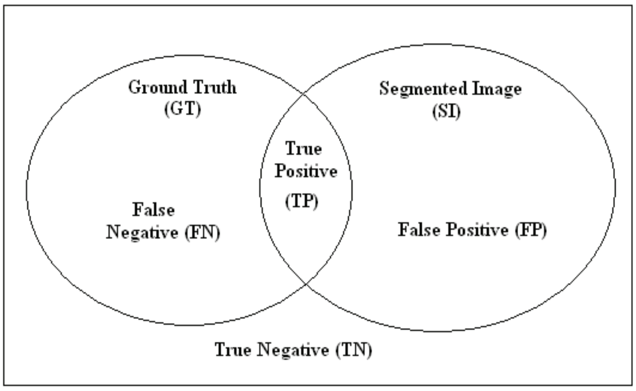


Fig. 4. Illustration of overlapping between SI and GT

In order to assess the accuracy of image segmentation, the value of *TPR* and *FPR* are calculated using

$$TPR = \frac{TP}{TP + FN} \tag{20}$$

and

$$FPR = \frac{FP}{TP + FP}. \tag{21}$$

An accurate segmentation result should have *TPR* close to 1, while *FPR* should be as low as possible. The image is said to be over segmented if the value of *TPR* is close to 1 and *FPR* value is too high.

While, Jaccard similarity index, *J(GT,SI)* is used to measure the overlapping of two sets. It can be defined as the size of the intersection of the sets divided by the size of their union, where

$$J(GT, SI) = \frac{|GT \cap SI|}{|GT \cup SI|}. \tag{22}$$

The Jaccard index is equal to zero if the two sets are disjoint, and is one if they are identical. Higher index number indicates better image segmentation results. The goal is to get as close to 1 as possible.

Dice similarity index, DS is just like Jaccard index. The index value is between 0 and 1. *DS* is defined as

$$DS = 2\frac{|GT \cap SI|}{|GT| + |SI|}. \tag{23}$$

Absolute error ratio, r_{err} is defined as the ratio between the absolute error, n_{diff}, and the total number of pixels, *N*, of an image. n_{diff} is the absolute different in the number of pixels between segmented image and the ground truth. The smaller error ratio value indicates a better image segmentation. r_{err} is calculated in percentage and is given by

$$r_{err} = \frac{n_{diff}}{N} \times 100\%. \tag{24}$$

Table 1 shows the comparison of segmentation performance for both original and enhanced images using the above mentioned methods. The performance analysis is based on the average of 39 samples of infrared images. The experiment results show that the proposed image enhancement method provides some improvement on image segmentation result. As illustrated in Table 1, it is evident that Otsu thresholding method with the proposed enhancement method provides a significant improvement on image segmentation. This method produces better warm regions segmentation with the value of *FPR* and r_{err} as low as 0.168 and 0.338 %, respectively. Without image enhancement, the segmentation of original image using Otsu method can be classified as over-segmentation. This situation occurs since the value of *TPR* is equal to 1 and *FPR* value is too high.

However, Hamadani and Kapur methods have no major effect from the enhanced image. Through experiment for all tested images using Hamadani and Kapur methods, the segmentation accuracy is not exceed more than 10% even after applying the proposed image enhancement technique. There is some improvement for MET segmentation method when applying the image enhancement. Nevertheless, the segmentation result for MET method is considerably not accurate as compared to GT image.

Image enhancement also brings some improvement for FCM segmentation. For the original image, FCM tends to give over-segmentation most of the image. Conversely, after implementing image enhancement, FCM yields under-segmentation result. For all tested images, the value of *FPR* is close to 0 while the value of *TPR* is less than 1which indicate that the image is under-segmented.

Overall, after implementing image enhancement based on the proposed technique, Otsu thresholding method give the best result for extracting the warm regions in infrared image. This is followed by Kapur and Hamadani method. FCM seems like to show a good result initially, but under-segmentation has been identified after doing performance analysis. MET has not shown a good result at all for both original and enhanced image which it tends to produce over-segmentation.

Table 1. Segmentation performance analysis

Image	Method	TPR	FPR	r_{err} (100%)	Jac.	DS
Original image	Otsu	1.00	15.81	38.32	0.061	0.115
	Hamadani	0.99	0.207	0.599	0.841	0.91
	Kapur	0.99	0.163	0.43	0.861	0.925
	MET	0.889	11.88	36.17	0.409	0.476
	FCM	1.00	11.76	27.25	0.089	0.163
Enhanced image	Otsu	1.00	0.168	0.338	0.874	0.928
	Hamadani	0.99	0.208	0.597	0.840	0.91
	Kapur	0.999	0.146	0.377	0.873	0.932
	MET	1.00	3.912	11.84	0.204	0.338
	FCM	0.791	0.05	0.478	0.791	0.881

Conclusions

This paper has proposed a technique for enhancing the infrared image by adjusting its intensity. By adjusting the pixel intensity could minimize the effect of background noises and enhancing the target region in the infrared image of electrical equipment. Through experiment, it was found that, Otsu method is outperformed over other segmentation methods after applying the proposed infrared image enhancement technique. To conclude, image enhancement is a useful technique for improving the thermal anomaly detection in electrical equipment. Accurate segmentation of infrared image can be extended for further study on analyzing the reliability of electrical equipment.

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Thermal anomalies in electrical equipments can be extracted if its infrared image is segmented properly. However, segmenting the infrared image is a very challenging task due to blur and low quality of the obtained images. So, it is very important to enhance the image prior to segmentation. This paper proposes an image enhancement method by adjusting the intensity of the image. Firstly, the intensity of the original image is inverted. Then, the warm region is enhanced by subtracting the original image with the inverted image. Experimental results through different segmentation algorithms show that by enhancing the infrared image using the proposed algorithm could improve the segmentation performance. Ill. 4, bibl. 16, tabl. 1 (in English; abstracts in English and Lithuanian).

M. S. Jadin, S. Taib. Termovaizdo pagerinimas ir segmentavimas išskiriant termines anomalijas elektros įrangoje // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 4(120). – P. 107–112.

Terminės anomalijos elektros įrangoje gali būti išskirtos, jei jos terminis atvaizdas yra tinkamai segmentuotas. Tačiau terminio atvaizdo segmentavimas yra labai sudėtingas uždavinys dėl neryškaus ar blogos kokybės atvaizdo. Todėl labai svarbu pagerinti atvaizdą prieš segmentavimą. Siūloma atvaizdą pagerinti keičiant jo intensyvumą. Pirmiausia originalaus atvaizdo intensyvumas yra invertuojamas, tada šiltos sritys yra pagerinamos iš originalaus atvaizdo atimant invertuotą. Eksperimentai parodė, kad siūlomu metodu, galima pagerinti atvaizdo segmentavimo našumą. Il. 4, bibl. 16, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).