Defect Detection in Thermal Image using Thresholding Technique

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Abstract: - This paper proposes a technique to detect defects as depicted in a thermal image. The technique is based on a local neighborhood pixel operation using kernel window 3×3. All pixels within this window will be mapped to only a single pixel value. Next, the thresholding technique is used. The main focus of the employed thresholding technique is the popular Otsu method and testing with other global thresholding technique is also given in the text. From the results obtained, it is shown that the proposed method is able to detect defects occur in a thermal image using any standard thresholding technique which is not designed for thermal images. The technique is easy to implement yet the result is promising.

Key-Words: - Defect detection, Thermal image, Kernel operation, Thresholding, Otsu method

1 Introduction

Thermal image is an image of an object as a function of the radiated energy captured by a thermal camera [1]. This term comes from the infrared thermography (IRT) technology [2]. IRT has gained its popularity in the last few decades over other predictive maintenance techniques due to its many advantages. It is contactless, easy to interpret the thermal data, large area of inspection, free from dangerous of radiation, and has been successfully applied to solve many real world problems.

Raw data captured by a thermal camera is in the form of temperature values. Thermal camera manufacturers usually have their own software to read this data and display them as a thermal image. When converting temperature values into a thermal image, a pseudo-coloring or false-coloring technique [3] is used. Certain color level represents certain temperature values. In this software terminology, this color map is called *palette*.

In a thermal image, a defective area or an area with the hottest temperature is usually represented by the brightest color. Rather than working in a colored thermal image, this paper takes the advantage of using a grayscale thermal image, since the defective area is still obvious in this image mode.

Few efforts have been done by researchers for object detection in a thermal image. Some methods use the thresholding technique for the detection, and others employ other criterion.

Hamadani [4] employed a first order statistics properties, mean μ and standard deviation σ, to extract a *warm* object in a thermal image. The threshold level is given by $T = k_1 \times \mu + k_2 \times \sigma$.

Maldague *et al.*, [5] developed two step algorithms for defect extraction in thermal images. Firstly, the locations of the defects (seeds) are found. Secondly, a specific threshold is obtained for each of the defects detected by region-growing around those seeds. The thresholding criterion for seed finding is $T = \alpha \times (\mu + \alpha \times \sigma)$.

Araki *et al.*, [6] used *fuzzy c-means* clustering algorithm to segment occupants in a room using a thermal image. Fuzzy c-means was first applied to remove the background, and then *peak-climbing* algorithm was used to identify the number of occupants, followed by a *region growing* algorithm for accurate segmentation. It used three main algorithms in the segmentation process; hence the cost is expensive from processing time perspective.

Other methods can be found in the literature [7-11]. The methods in [4-5], [7-8] employed the thresholding philosophy to extract the desired object in a thermal image. They developed a typical thresholding algorithm to solve their thermal image problem. Any standard thresholding algorithm which is developed for intensities image may not be suitable for thermal image application [7].

Similar to any established thermal image thresholding techniques, this paper takes the advantage of the thresholding technique to detect the defect that may occur in a thermal image. This paper is not about developing a new thresholding algorithm; rather it deals with how to implement any thresholding techniques to a thermal image, something they are not designed for. The classical Otsu thresholding technique is the main focus. For verification, we also employ Ridler's technique [15].

This paper is organized as follow: in the next section, Otsu thresholding technique is discussed. In section 3, the proposed method is described. The last two sections are focused on the obtained results and the conclusions.

2 Otsu Thresholding

Otsu [12] proposed a thresholding technique based on the discriminant function. Despite of its limitation (as described by Kittler and Illingworth [13]), this technique is very popular and has applied to various applications [14], mainly for document processing.

In Otsu method, an image with gray level histogram $\{p_i\}_{i=0}^{L}$ is thresholded at T gray level value. The probabilities of background and foreground of the T-thresholded image can be calculated:

$$P_B^T = \sum_{i=0}^{T} p_i \quad \text{and} \quad P_F^T = 1 - P_B^T = \sum_{i=T+1}^{L-1} p_i \tag{1}$$

From Equation (1), the means and variances associated with the background and the foreground can be further calculated by:

$$\mu_B^T = \frac{\sum_{i=0}^{T} i \times p_i}{P_B^T} \tag{2}$$

$$\mu_F^T = \frac{\sum_{i=T+1}^{L-1} i \times p_i}{P_F^T} \tag{3}$$

$$v_B^T = \frac{\sum_{i=0}^{T} \left(i - \mu_B^T\right)^2 \times p_i}{P_B^T} \tag{4}$$

$$v_F^T = \frac{\sum_{i=T+1}^{L-1} \left(i - \mu_F^T\right)^2 \times p_i}{P_F^T} \tag{5}$$

Between-class and *within-class variance* can then be defined as:

$$v_{between-class}^T = P_B^T \times P_F^T \times \left(\mu_B^T - \mu_F^T\right)^2 \tag{6}$$

$$v_{within-class}^T = P_B^T \times v_B^T + P_F^T \times v_F^T \tag{7}$$

Optimum thresholding value in Otsu method is determined by maximizing $v_{between-class}^T$ or minimizing $v_{within-class}^T$.

Since Otsu thresholding technique was not specifically designed for thermal images, it cannot detect the defects in this kind of images successfully. Fig.1 shows an illustrative example of this problem.

(a) (b) (c)

Fig.1 (a) Grayscale thermal image, (b) ground-truth thresholded image, (c) Otsu method

3 Local Intensities Weighting (LIW)

Otsu method assumed that the criterion function as in Eq. (6) was always unimodal, but as shown by Kittler and Illingworth [13] that this assumption is not always hold in general. They showed some class of image statistics: unimodal, bimodal, trimodal, or multimodal and the Otsu criterion function for this kind of images is not always unimodal. They proposed another criterions supposing that the criterion function of Otsu method of an image is not unimodal. It was also stated that the unimodal histogram will be characterized by a unimodal objective function of Otsu method.

In thresholding the image, the Otsu method used the histogram of image. The criterion function is derived from this histogram. Rather than proposing a new criterion to improve Otsu method (as done by Kittler and Illingworth [13]), this paper takes on a different strategy. The idea is to make the thermal image always has the unimodal histogram. To achieve this, a local neighborhood operation (which we call *LIW*) is applied to the thermal image before passing it to the Otsu method for detection of the defect.

This technique will brighten the bright area and darken the dark area. It is assumed that the defect is represented by the brighter area, and the background or sound area is the darker area. Therefore, the defective pixels will be shifted to 255 and non-defective pixels tend to 0 values (for an 8-bit system).

Consider a pixel *f(i, j)* in a thermal image with its 8-connectivity configuration as shown in Fig.2, where *z1 = f(i-1, j-1), z2 = f(i-1, j), z3 = f(i-1, j+1), z4 = f(i, j-1), z5 = f(i, j), z6 = f(i, j+1), z7 = f(i+1, j-1), z8 = f(i+1, j),* and *z9 = f(i+1, j+1).*

z1	***z2***	***z3***
z4	***z5***	***z6***
z7	***z8***	***z9***

Fig.2 LIW window

Weighted intensities pixel *g(i, j)* for a new image is defined as a multiplication of the pixels reside in the local window as defined in Eq. (8). Fig.3 illustrates the weighting process. This is done through out the entire image as a convolution process. These values are then normalized by dividing with the maximum value.

$$g(i,j) = z1*z2*z3*z4*z5*z6*z7*z8*z9 \qquad (8)$$

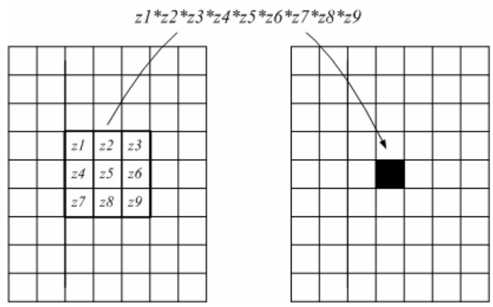


Fig.3 LIW operation

This process is repeated until the defect is isolated and easy to be detected by Otsu method. The first LIW operation to the original thermal image will be called as the 1^{st} level LIW, the next LIW operation onto this 1^{st} level LIW will be called as the 2^{nd} level LIW, and so forth.

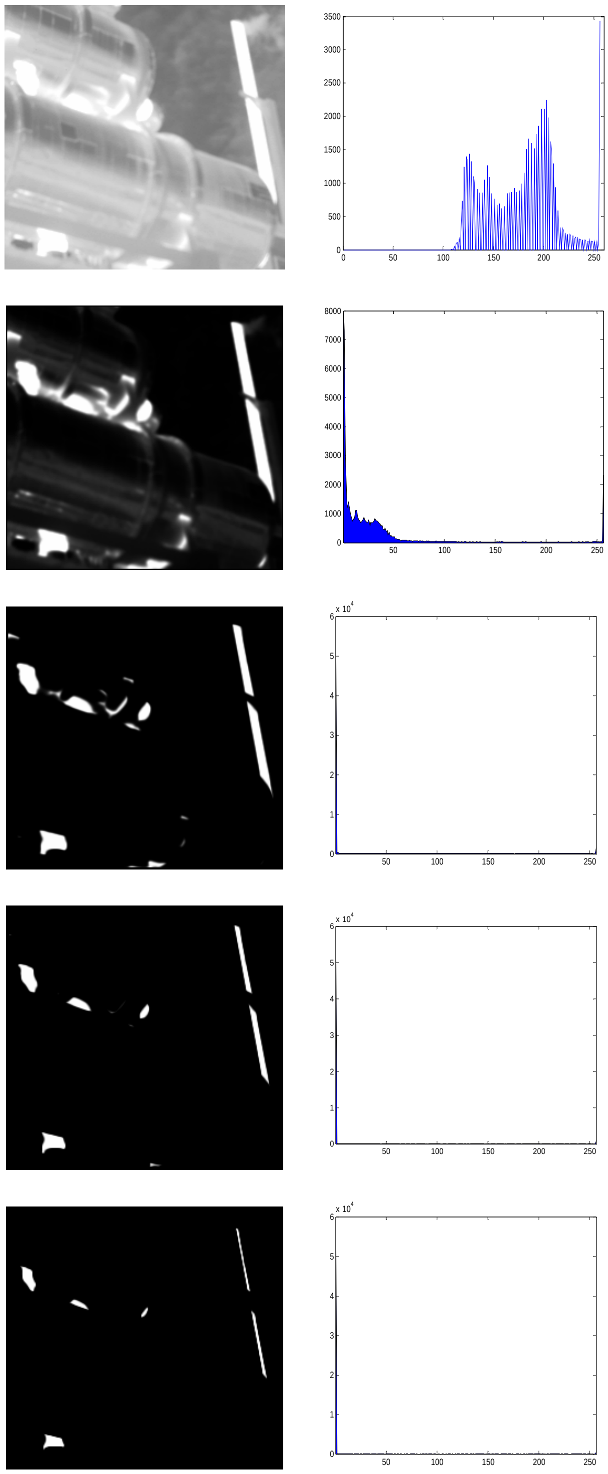
Fig. 4 shows a thermal image after applying LIW operator using four levels. It is clear that at every level LIW tends to shrink the defect. In order to keep the defect shape, morphological dilation (with 3×3 square structuring element) can be applied after each level of LIW operation, or alternatively applying it several times (according to numbers of applied levels) in the last LIW image operation.

From the histogram of the image after LIW operation, the pixels have been shifted to the dark area which makes the image become unimodal (in fact it is not purely unimodal at the 1^{st} level LIW) and consequently helps to make the Otsu criterion function becomes unimodal. This situation makes it possible to apply the Otsu thresholding technique to detect the defect in a thermal image.

4 Discussions

As already shown in Fig.4, LIW operation will darken the dark pixels while preserve the bright pixels.

Fig.5 shows the detection of the defect in thermal images without LIW operation and with LIW operation. It is clear that the defect within LIW thermal image can be detected successfully by Otsu method. Even other method which was not specifically designed for thermal images (Ridler [15]) can work well for detecting the defect. It is worthy to note that from Fig.5 we found that to achieve successful result at least we need to employ two levels LIW operation.



(a) (b)

Fig.4 (from top to bottom): original thermal image and its LIW image from 1st to 4th level along with its histogram

5 Conclusions

This paper proposes a technique to detect the defect which may occur in a thermal image using the local intensities weighting (LIW) operation. A 3×3 kernel window is used to weight the local new pixel of thermal image. Normalization is then applied to make this LIW image in the 8-bits format image (to simplify the computational cost).

It has been shown that any defect within this LIW thermal image can easily be detected by any thresholding algorithms which are also shown in Fig.5.

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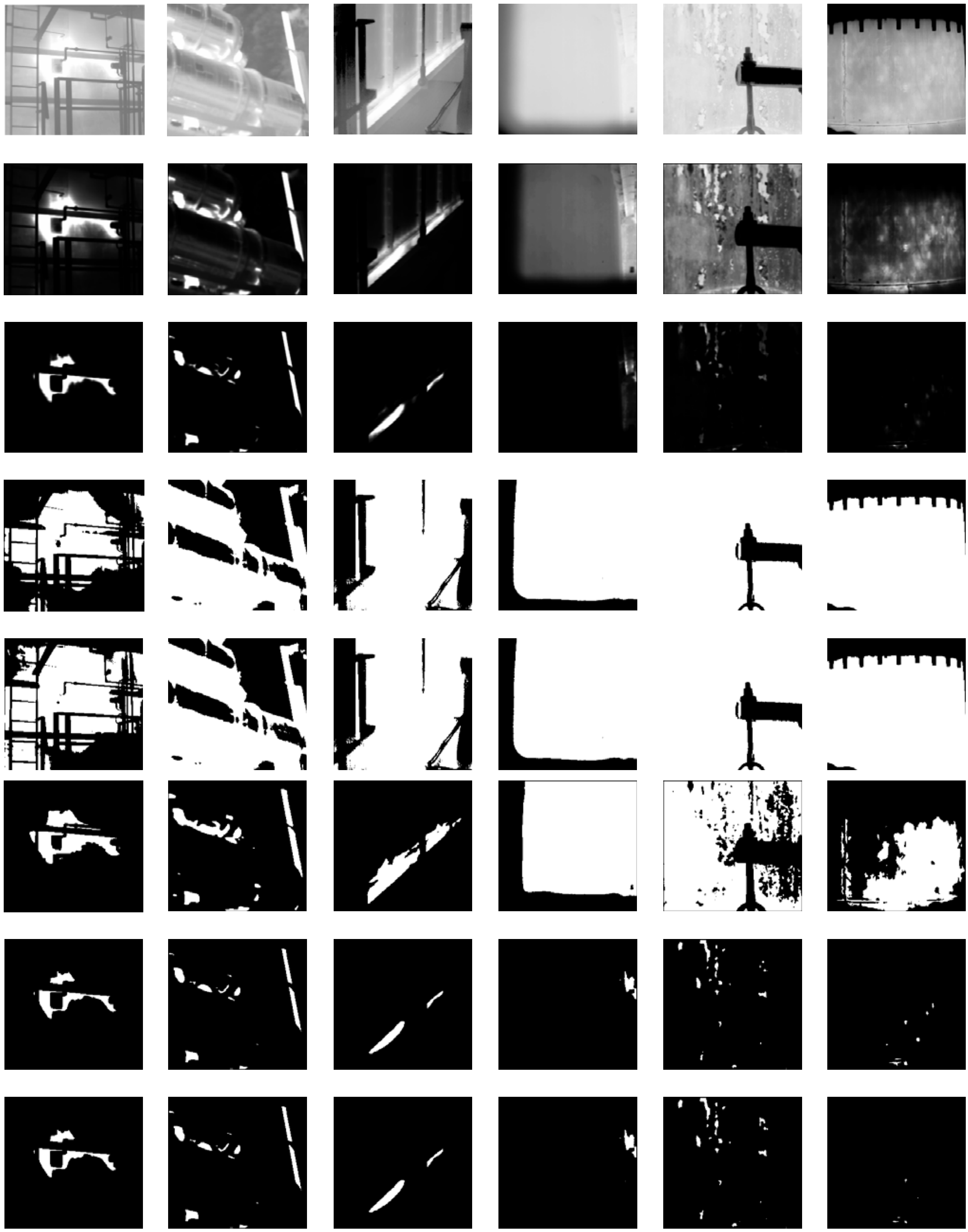

Fig.5 (from top to bottom): original grayscale thermal image, 1st level LIW image, 2nd level LIW image, original image thresholded with Otsu, original image thresholded with Ridler, 1st level LIW thresholded with Otsu, 2nd level LIW thresholded with Otsu, 2nd level LIW thresholded with Ridler thresholding