A Novel Method for Surface Defect Inspection of Optic Cable with Short-Wave Infrared Illuminance

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Abstract: Intelligent on-line detection of cable quality is a crucial issue in optic cable factory, and defects on the surface of optic cable can dramatically depress cable grade. Manual inspection in optic cable quality cannot catch up with the development of optic cable industry due to its low detection efficiency and huge human cost. Therefore, real-time is highly demanded by industry in order to replace the subjective and repetitive process of manual inspection. For this reason, automatic cable defect inspection has been a trend. In this paper, a novel method for surface defect inspection of optic cable with short-wave infrared illuminance is presented. The special condition of short-wave infrared can not only provide illumination compensation for the weak illumination environment, but also can avoid the problem of exposure when using visible light illuminance, which affects the accuracy of inspection algorithm. A series of image processing algorithms are set up to analyze cable image for the verification of real-time and veracity of the detection method. Unlike some existing detection algorithms which concentrate on the characteristics of defects with an active search way, the proposed method removes the non-defective areas of the image passively at the same time of image processing, which reduces a large amount of computation. OTSU algorithm is used to convert the gray image to the binary image. Furthermore, a threshold window is designed to eliminate the fake defects, and the threshold represents the considered minimum size of defects ε . Besides, a new regional suppression method is proposed to deal with the edge burrs of the cable, which shows the superior performance compared with that of Open-Close operation of mathematical morphological in the boundary processing. Experimental results of 10000 samples show that the rates of miss detection and false detection are 2.35% and 0.78% respectively when ε equals to 0.5mm, and the average processing period of one frame image is 2.39ms. All the improvements have been verified in the paper to show the ability of our inspection method for optic cable.

Keywords: defects inspection, optic cable, image processing, infrared illuminance

1. Introduction

Along with the construction of broadband network, especially the vigorously deploy of the fourth and the upcoming fifth generation of networks, the market of optical fiber and cable industry has entered a period of vigorous development. During

the manufacture process, surface deflection of optic cable is a common technical difficulty caused by materials or improper workmanship. These defects not only affect the physical strength of the cables which may lead to the damage of internal fiber, but also make some optical properties changing, such as dispersion loss of fiber. Thus, the defects must be found out before the products are reached to the user. Traditional surface detection methods which used the spark detector are applicable to conventional metal sheathed cable. For the whole dielectric and alien surface structure cables (such as air-blowing micro-cables or fiber optic cables for access network, etc.), it can only be checked by means of manual rewind or human observation to detect the position of stripping or bulge defects. However, manual inspection in industrial manufacturing has low detection efficiency and costs a lot of manpower and resources. Therefore, it is of great practical significance to design a low cost, reliable, real-time and high veracity of automation method for defects inspection of optic cable. And the machine vision technology provides a viable solution to the issue.

Machine vision refers to the industrial application of vision technology. It describes the understanding and interpretation of technically obtained images for controlling production processes^[1,2]. Currently, machine vision is widely used in industrial manufacturing, especially in quality detection, such as web^[3,4], bottle^[5], metallic strips^[6], fabrication^[7], glass manufacture^[8,9], etc. Ref. [10] designed two matched Gabor filters based on power spectrum of the textures of fabric, which was suitable for a regular texture images. Ref. [11] proposed an inspection algorithm based on contour comparison to satisfy the real-time and high accuracy defect inspection of printed circuit board (PCB) bare board, which was fit for standard shape defects in the target detection. However, for the optic cables making industry with high-automation, how to inspect the defective cables timely and effectively is a challenging work. And few researches of the image detection algorithms for the cables had been reported.

In this paper, we propose a new method for surface defects inspection of optic cable with short-wave infrared illuminance which is based on image processing. To detect cable's surface defects, we first need to choose appropriate illuminance to enhance the features of images. To the best of our knowledge, it has been rarely reported that defects detection system uses short-wave infrared illuminance. Compared with previously reported inspection methods based on visible light illuminance^[16], our form of illuminance has the following advantages: first, it can provide illumination compensation under the weak illumination environment in order to ensure the correct detection. Second, it is a relatively stable form of illuminance. Therefore, it won't exist the case of exposure that appeared in visible light illuminance, which affects the veracity of inspection algorithm. Besides the accuracy of detection method, real-time performance is also highly desirable for industrial application. However, some existing algorithms generally focus on the defects with an active searching method, such as wavelet based techniques, the neural net algorithm, statistical approach, etc.^[1,12-17], which are time-consuming. For example, Ref. [9] classified two types of the blister based on information of area, boundary, length, etc., which were extracted from the binary images. Ref. [14] proposed the wavelet packet

decomposition algorithm to solve the similar problem. In literature [18], Lin presented an automatic visual inspection of ripple defects using wavelet characteristic based multivariate statistical approach. He applied multivariate statistics of Hotelling T^2 , Mahalanobis distance D^2 , and Chi-square X^2 , respectively, to integrate the multiple texture features and the three wavelet-based multivariate statistical models. This method was based on feature extraction from wavelet-domain images for defect detection. In contrast, our method is carried out in a passive detection way. We don't appreciate that what the defects are and the characteristics of them. We eliminate the non-defective areas while in image processing, and leave the considered defects finally. In addition to improve the processing speed of the algorithm, we also aim to eliminate fake defects such as edge burr on the edge of the cables, as shown in Fig.1, where the edge burrs were mis-detected as defects marked by red-lines, and the true defects were circled by yellow-lines.

Fig.1 Possible defects image of an optic cable under short-wave infrared illuminance

The rest of the paper is organized as follows. In section 2, preliminary principle of the newly raised inspection algorithm are introduced. Those include the analysis of performance requirements, and the detailed process of algorithm. In section 3, experimental results on a large number of sample images are reported. Section 4 gives a conclusion, followed by future works.

2. Principle and process of inspection algorithm

2.1 The analysis of performance requirements of detection algorithm

Usually, a good optic cable has a stable reflection property. If defects appear, light path and light power will be changed due to the change of cable's optical character around defects. These changes lead to the variation of gray levels of image incepted by industrial cameras. During the manufacturing process, the conveyor speed of cable is generally 1~2.5m/s. To ensure that all surface defects of the fiber photographed, the frame rate of cameras is set to 100 images per second. Our system uses four cameras which are simultaneously placed in the four directions of the fiber optic cables, then 400 images should be processed timely within one second. And the

processing time of each frame should be controlled within 2.5ms.

Consequently, detection algorithm should not only ensure the accuracy of the detection but also meet the requirements of real-time performance of the system. Considering from the image features and real-time processing, the image processing flow is illustrated in Fig.2, which is composed of two parts of image segmentation and defect recognition. In this section, we will describe these two processes procedures step by step to illustrate the effect of our method.

Fig.2 Block diagram of image processing

2.2 Image Segmentation

In this paper, we simulate the actual scene of industrial detection with short-wave infrared illuminance. Before extracting image features, we perform binary preprocessing with an appropriate threshold^[11] to distinguish the foreground and background domain of image. We choose the OTSU algorithm^[19] to convert the gray image to the binary image as the method of threshold segmentation^[20-22] due to its good adaptability.

The OTSU algorithm uses the gray histogram of image to dynamically determine the optimal threshold segmentation through the maximum variance between the foregrounds and backgrounds, therefore a corresponding binary image could be obtained. The maximum variance means the minimum probability of misclassification. Suppose that L is the grayscale of image, then its pixels can be divided into two categories, C_0 and C_1 , the probability of which can be described by the following equations respectively.

$$w_0 = P_r(C_0) = \sum_{i=0}^L p(i) \quad (1)$$

$$w_1 = P_r(C_1) = \sum_{i=t+1}^{L-1} p(i) \quad (2)$$

Where, $p(i) (i = 0, 1, 2, \dots, L-1)$ is the probability of pixels with i th grayscale.

w_0 denotes the proportion of pixels that belong to foreground domain, while w_1 is that of background.

Assume that the Gray-mean-square-error (GMSE) of the whole image is expressed as μ . Then the variance between the two categories, σ_B^2 , can be defined as.

$$\sigma_B^2 = w_0 (\mu_0 - \mu)^2 + w_1 (\mu_1 - \mu)^2 \quad (3)$$

Where, μ_0 and μ_1 represent the GMSE of the foreground and background respectively. In order to evaluate the merits, we introduce a judge function of threshold value.

$$\varphi_t(t^*) = \text{Argmax}_{0 \leq t \leq L-1} (\sigma_B^2) \quad (4)$$

Here, t^* is the optimal threshold segmentation that our algorithm expected to convert the gray image to binary image when σ_B^2 reaches maximum value.

Fig.3 The original image

Fig.4 Binary image after threshold segmentation

2.3 Defect Recognition

As shown in Fig.4, a clear binary image is obtained after threshold segmentation, but this image still includes background noises, fake defects, and edge burr. To remove these negative factors and the false defects, the gray defect image must be segmented two times with different threshold values, one for binary image in Sect.2.2, and the other for rejecting fake defects in this section. Therefore, the part of defect recognition includes two steps of rejecting fake defects and boundary processing.

2.3.1 Rejecting Fake Defects

Supposing that the minimum size of defects that a system requires to recognize is $\varepsilon \text{ mm} \times \varepsilon \text{ mm}$. Then the lowest resolution should satisfy a pixel corresponding to $\varepsilon^2 \text{ mm}^2$. Generally, in order to improve the accuracy of detection, we will make a pixel corresponding to $\delta^2 \text{ mm}^2$ ($\delta < \varepsilon$) for a certain amount of redundancy. Assume that the number of pixels of the smallest defects related is P , which is selected as the fixed threshold to segment the true and fake defects, and it can be expressed as:

$$P = \lceil \varepsilon / \delta \rceil \quad (5)$$

Then the algorithm of rejecting fake defects can be described as:

- (1) Finding neighborhood connected domain of figure 3.
- (2) Calculating the area of each connected domain, represented as S_k ($k = 1, 2, \dots, N$).

(3) The result image processed by defects filtration, should satisfy the following requirements.

$$f(i) = B, S_k < P \quad (6)$$

Where, B denotes the gray value of background domain, which is equal to 0 under the condition of the paper. The connected domain whose area is less than the threshold value P are regarded as fake defects pixels, and their gray level is changed to 0, otherwise changed to 255. Fig.5 shows the processing result of false defect in Fig.4, which left the true defects accurately.

In this paper, the minimum size of defects ε in equation (5) can be set according to customer's demand. It is one of the advantages of our detection method.

Fig.5 Binary image after defects filtration

2.3.2 Boundary Processing

In the boundary processing, we apply two methods giving the contrast analysis of boundary information of fiber cable image. One is the Open-Close operation in mathematical morphological, and the other is the method presented to suppress the structures connected to image border, which we called regional suppression method.

A. The Open-Close Operation

The opening operation can remove the small protruding portions. The closing operation generally fill the tiny hole and connect adjacent object to smooth the boundary. The method is characterized by the following equation, where equation (7) is opening operation expression and equation (8) is closing operation expression.

$$A \circ B = (A \ominus B) \oplus B \quad (7)$$

$$A \circ B = (A \oplus B) \ominus B \quad (8)$$

The result in Fig.6 shows that the application of closing operation and opening operation orderly for processing Fig.5. As can be seen from Fig.6, the image processing result fully meets the needs of identifying the real flaws and removing the background noise, but the edge burrs still exist. Since there are four cameras located in both vertical and horizontal directions of the fiber cable, that means, the cable edges photographed in one camera are located in the middle of the image in another camera, we can deal with the edge of cable as a flawless. Even it really has some defects on the cable edges in one image of one camera, it will be detected in the middle of another image in another camera. The following will remove the non-defective parts of the cable edges through the regional suppression method.

B. Regional suppression method

Regional suppression method suppresses the structures elements that are lighter than their surroundings and that are connected to the image border. A clear result image is obtained by leaving only real defects as shown in Fig.7, which is fully consistent with the demand of recognizing the real drawbacks in Fig.1. And the

detection rate is 100 percent.

Fig.6 Traditional closing and opening operation for boundary processing

Fig.7 Regional suppression method for boundary processing

3. Experiment and results

The proposed detection method succeeds in processing the images of fiber optic cables, and detecting defects of them. In this paper, we used more than 10000 defect samples that were obtained from an optic cables manufacture to verify the feasibility and effect of the proposed detection method. The average processing period of one frame image with the dimension of 400×1000 is 2.39ms. And it can meet max fabrication speed achieving 150m/min. Moreover, some examples are shown in Fig.8, where Fig.8 (a)~(d) are the original defect images. It can be seen that, there are many small water droplets on the defect images, which should be ignored completely and just detect the true defects marked by yellow-lines in Fig.8 (a)~(d). Fig.8 (e)~(g) are corresponding detecting results of Fig.8 (a)~(d) through our inspection method. The experimental platform was on Windows 10 professional edition, Inter Core i7-4710MQ @ 2.5 GHz, 64-bit operating system, and 16GB RAM.

Fig.8 Some examples in the experiment data. Left: the original defect images. Right: the corresponding processing results.

3.1 Detection results comparison

To validate the performance of our inspection method, we tested the effect of our algorithm and compared it to the wavelet-based T^2 statistical method proposed by Lin^[18].

It can be seen from Fig.9, both methods can detect the true defects without omission. However, Lin's wavelet-based T^2 statistical method got a quite high rate of false detection because quite a number of non-defective areas, such as the small water droplets, were mistaken as defects in Fig.9 (e)-(h). The proposed method don't have this problem because we do not extract features of defects but eliminate the non-defective areas while in image processing, and just leave the true defects finally, as shown in Fig.9 (i)-(l). Thus it can be seen, our algorithm has the advantage of higher precision, which makes it much suitable for the surface defect inspection of optic cable.

Fig. 9 Results comparison of our method and Lin's wavelet-based T^2 statistical method. (a), (b) and (d) Three defect images of optic cables. (c) Faultless image with some small water droplets. The true and fake defects are marked by yellow and red lines, respectively. (e)-(h) Detection results of (a)-(d) by Lin's wavelet-based T^2 statistical method. (i)-(l) Detection results of (a)-(d) by proposed method.

3.2 Research on the rates of false detection and miss detection

For a surface defects detection method of optic cables, there are two important technique indexes, the rates of false detection and miss detection, which are both associated with the value of ε in equation (5). Usually, to ensure the quality of products, manufactures requires the rate of miss detection as small as possible, which makes the value of ε should be set as small as possible. However, the smaller size of defects it set, the more false defects will be identified. It will result in the increase of the rate of miss detection.

In order to achieve a balance between the rate of false detection and miss detection. The inspection results were verified time after time by contrast with offline inspection. The number of defects detected by manual inspection is 253, and there are two miss defects. Then the total number of true defects N is equal to 255.

Suppose that the number of defects found by the inspection algorithm can be denoted by M , and the true, the false, and the miss defects can be represented by t , m and u respectively, then they will meet the following conditions.

$$\begin{cases} t + m = M \\ t + u = N \end{cases} \quad (9)$$

Fig. 10 shows an example of inspection result with different value of ε , and the other experiment result of 10000 samples through our method is summarized in table 1.

Fig. 10 Example of inspection result with different value of ε

Table. 1 The inspection result of the proposed algorithm

The minimum defects ε / (mm)	Defects number found by our method / M	True defects number / t	Miss defects number / u	False defects number / m	The rate of miss detection (%)	The rate of false detection (%)
0.1	457	255	0	202	0	79.22
0.2	378	255	0	123	0	48.24
0.3	309	253	2	56	0.78	21.96
0.5	251	249	6	2	2.35	0.78
0.7	109	108	147	1	57.65	0.39
0.9	87	87	168	0	65.88	0

The results of the experiment indicate that: this inspection algorithm not only can eliminate the influence of fake defects such as edge burr on the edge of cables effectively but also can ensure detect exactly, which includes holes, beat, bubble,

necking, scratches, discoloration and so on. Moreover, the average processing period of one frame image is 2.39ms, which fully satisfies the requirement of real-time performance of the industrial production. In Table 1 we can see that, there is no mistake reports when ε is 0.9, and no missing flaws when ε is 0.1 or 0.2. Additionally, the rates of miss detection and false detection are 2.35% and 0.78% respectively. It achieves balance when ε equals to 0.5 in this case. As shown in Fig.11, it is the graph of the roughly variation of the number of miss and false defects with different ε . The number of false detects reduces and the miss detects increases when ε increasing. It can be seen that, the number of false detects nearly converges to zero when the minimum defects is bigger than 0.7mm. It presents an opposite correlation tendency totally.

Fig. 11 The graph of the roughly variation of the number of miss and false defects with different ε

4. Conclusion and future work

A novel real-time optic cable defect inspection method with short-wave infrared illuminance was proposed in this paper. This method was implemented in the short-wave infrared illuminance innovatively. And it eliminated the non-defective areas at the same time of image processing to reduce the computational cost. The detection algorithm is described as follows. As a first step, the foreground and background domain of initial image are segmented with OTSU algorithm, of which the optimal threshold is expected to convert the gray image to the binary image. Then, fake defects are eliminated through our method with a free setting threshold window, which is different from the previous threshold. Finally, a new regional suppression method was proposed and compared its performance with that of Open-Close operation of mathematical morphological in the boundary processing. It exhibits a great distinct advantage when dealing with edge burrs of the image. And we tested the wavelet-based T^2 statistical method proposed by Lin^[18] in section 3.1 and compared

its detection effects with our algorithm by detecting some defect images of optic cables. The results of comparison shows that our method has more superior performance for defect inspection of optic cable due to its higher veracity.

In addition, the experimental results of 10000 defect samples show that our algorithm has the advantage of high accuracy, high real-time ability and better effect of edge processing. Furthermore, a threshold window was designed in our inspection method, which realized the interaction framework. All the improvements make the proposed method much suitable for the system of surface defect inspection of optic cable.

As a future work, the inspection system based on the proposed method will be implemented an experimented.

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