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Surface splicing defect analysis and application of polarization maintaining fiber using graph cut with illumination priors

Haoting Liu [a,*], Wei Wang [a], Feng Gao [a], Jie Li [b], Kai Chen [c]

[a] China Academy of Aerospace Electronics Technology, Fengying East Road No. 1, Haidian District, Beijing 100094, China
[b] Astronaut Research and Training Center of China, Yuanmingyuan West Road No. 1, Haidian District, Beijing 100094, China
[c] Satellite Maritime Tracking and Control Department of China, Mail-Box 103-203, Jiangyin 214431, China

HIGHLIGHTS

- We propose a new graph cut model with illumination shape priors.
- We use our proposed graph cut model to segmentation fiber splicing defect.
- We use SVM classifier to evaluate the fiber splicing effect.
- We use the splicing defect feature as a new factor to evaluate the splicing effect.

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ABSTRACT

A new surface splicing defect analysis and application technique of Polarization Maintaining (PM) fiber is proposed. In contrast to the traditional artificial experience based analysis method, we not only develop an automatic defect segmentation technique for the fiber splicer but utilize the image features of splicing defect to assist evaluation of the splicing effect. First, we employ a standard fiber splicer to implement the splicing operation. Both the visible and the hot (infrared) images are captured during that processes. Second, we use the image processing techniques to analyze the image features for both the visible and the hot images. The Hough line detection is used to monitor the core-offset or the angle tilt problems of spliced fibers in visible image. A new Graph Cut Model (GCM), which uses the Multivariate Gaussian Mixture Model (MGMM) as the illumination prior of transmitted rays, is employed to segment the splicing defect in hot image. Third, multiple defect image features, such as the linear edge, the defect shape, and the inertia moment are all computed for the description of defective region. Finally, the SVM classifier is employed to evaluate the fiber splicing effect. The defect features, the splice loss, the extinction ratio, together with the final precision output of optical component are utilized to train the SVM. By using this method, a reliable quality control measurement for the optical component of aerospace optoelectronic apparatus is developed. Many experiments have verified the validity of the proposed method.

1. Introduction

Polarization Maintaining (PM) fiber [1], as a kind of single-mode fiber, is a light transmission medium which can keep linear polarized-light propagated by the mode of linear polarization. A complete PM fiber at least includes there parts: the core, the cladding and the jacket. The jacket is an external protection of fiber; while only the core and the cladding accomplish the light transmission task. Traditionally, PM fiber uses the optics law of total reflection to work. With a proper incidence angle, the rays impinging on the core-cladding interface at an angle greater than the critical angle will be imprisoned in the interior of the core. Thus the reflection light can take complex coding message for information transmission of long distance. Because the light source is easy to produce and control, the material cost of fiber is cheap, and its size is also small; with these merits, PM fiber has attracted more and more attentions in many application fields, such as fiber communications or intelligent sensors [2].

In many situations it is needed to connect the separated ends of fiber together to accomplish special light transmission tasks. For example, when assembling the Fiber-Optic Gyroscope (FOG) [3] we need to splice the fiber-optic coil and the Y-junction optical waveguide together. One of best solutions for this issue is to use the fiber splicing machine to accomplish that task. When splicing fibers, the engineer has to peel off the fibers' jacket, clean the

* Corresponding author. Tel.: +86 010 88105074.
E-mail address: imkyran@hotmail.com (H. Liu).

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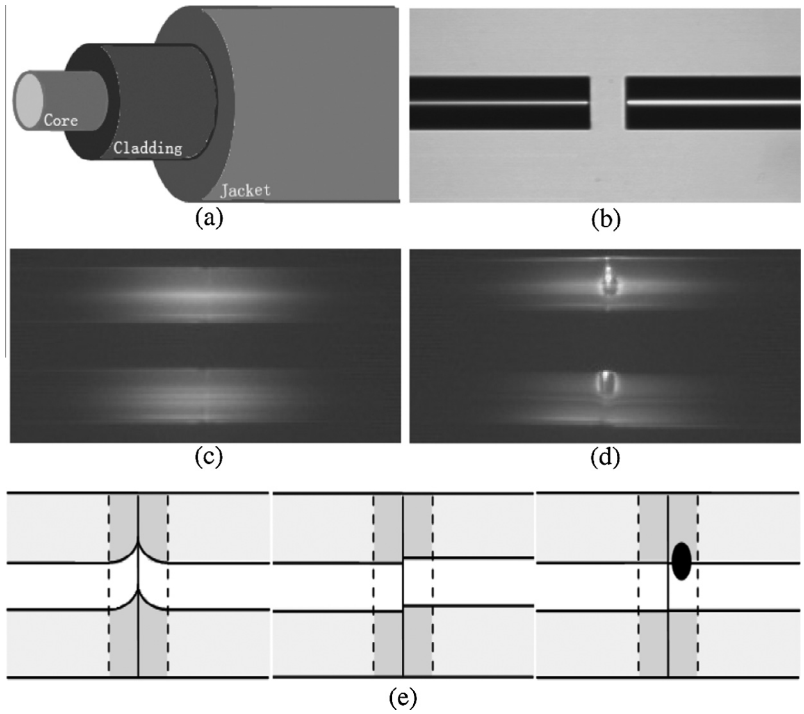

Fig. 1. Illustrations of fiber and its splicing defects.

surface of cladding, and then put it into the fiber splicer; they also need to monitor the entire splicing process and judge the splicing state all by their own experiences. Fig. 1(a) shows us the basic structure of a PM fiber. Image (b) Is the visible image of spliced fibers. Images (c) and (d) Give out the spliced samples of normal and defective modes respectively in hot (infrared) image forms. Image (e) Shows us the sketch map of some familiar errors when splicing fibers. In Fig. 1(c) and (d) we can see that the two white rectangles in the image center are the spliced fibers captured from vertical and horizontal directions respectively. If the cut edge is not smooth, or the fibers aim at each other with large offset; or some impurities are left in their splicing surfaces, all these problems will lead to the emergency of splicing defect invariably.

When assessing the splicing effect, in engineering, only the splice loss and the extinction ratio, which can be estimated by the fiber splicer directly, are considered as the most important evaluation factors [4,5] currently. The splice loss is a powers metric of the input and the output light across the fiber. It represents the energy loss during light propagation. Similarly, the extinction ratio describes the polarization maintaining ability of a PM fiber. In general, both the splice loss and the extinction ratio can be estimated by observing light powers inputted through the cladding on one side and its leak on the other side. However, in many practical cases, we would more like to use the Optical Time Domain Reflectometer (OTDR) to measure the splice loss rather than use the evaluation result of fiber splicer directly. This is because the output of splicer is only an approximate estimation of the actual situation. By considering the splice loss or the extinction ratio separately, we also cannot judge the splicing effect properly. In addition, if the splicing defect occurs, the situation becomes more complex. Currently, few estimation models consider the impact of splicing defect on the integrated splicing result. That will inevitably lead to an inaccurate assessment of the splicing effect.

In this paper we utilize the image processing techniques together with the pattern recognition theory to solve the problems of splicing defect segmentation and splicing effect evaluation. First, we use the standard splicer to realize the fiber splicing operation. During that process, the visible images and the hot (infrared) images are captured. Second, we employ Hough line detection method [6,7] to detect the core-offset and angle tilt problems of visible image. We also use the Graph Cut Model (GCM) [8,9] to segment the splicing defect of hot image. A novel GCM with illumination priors is proposed. The Multivariate Gaussian Mixture Model (MGMM) [10] is employed to imitate the highlighted region of transmitted rays. Third, we compute several region and contour features of the defect region. Finally, we employ the classic splicing effect evaluation indexes, the defect features, and the final precision output of the optical component to train a SVM [11] so that we can use it to forecast the splicing effect. By using our proposed quantitative method, the evaluation reliability and stability of splicing effect can be improved.

The main contributions of this paper include: (1) a novel energy function design method of GCM is proposed. Because of the cylinder shape and the glassy material of PM fiber, the MGMM is utilized to imitate the surface luminance distribution of transmitted light. (2) A new splicing effect evaluation technique for PM fiber is developed. The multiple splicing factors, including the splice loss, the extinction ratio, and the defect image features are all considered to evaluate the splicing effect by SVM.

In the following sections, first the splicing technique will be presented. Second the related image analysis method will be given. Third the splicing effect evaluation approach will be discussed. Finally, some experiment results will be shown.

2. PM fiber splicing technique

As we have stated above, before we use the fiber splicer, some manual operations, such as peeling off the jacket and cleaning the surface of cladding, are still needed. After we have put the remainders (cladding and core) into the slot of splicing machine, the splicer will control the rotation speed of driving axes and the push distance of two fibers, and then heat the fibers by current to realize a proper fusion. In general, the processes of splicing can be observed by cameras. The Polarization Observation by