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Automatic optical inspection system for the micro-lens of optical connector with fuzzy ratio analysis

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ABSTRACT

This study aimed to inspect micro-lens size of optical connectors. In imaging, it can be found that the edge of a micro-lens and sharpness of the base image are different from the images of a square or straight edge. The edge of a micro-lens may be fuzzy and its gray scale distribution map may present a downtrend, making it difficult to identify the edge position.

This study used a micro-lens with a diameter of 110 μm as a basis reference. Furthermore, a high-precision AFM was used to obtain accurate values. The measured results were substituted into a newly proposed fuzzy ratio analysis method to deduce the fuzzy ratio and adjust edge fuzzy functions for further analysis of the micro lens edge in order to obtain more accurate results, which were used for the inspection of optical connectors to improve measurement accuracy. The experiment demonstrated that the error between the study results and the results of the commercial measurement system is lower than 1 μm, and the inspection speed is faster.

1. Introduction

Currently, peripheral transmission interfaces of computers have been developed toward high speed. Based on fast optical transmission speed and top quality, new high-speed optical fiber 3C interface has introduced optical transmission (converged optical input/output modules) with high bandwidth starting at 10 Gb/s. Intel unveiled an interesting technology called Thunderbolt (or Light Peak) in the Intel Development Forum (IDF) in 2009. The technology incorporates optical cables into the USB (Universal Serial Bus), which will soon be used in signal transmission and high-speed optical signal transmission. To interconnect the USB interface, Intel developed a new connection method called converged input/output interface modules, or CIO modules. The interface module applies Free Space Optical Interconnects (FSOIs) for connecting, one to transmit, and one to receive, as shown in Fig. 1. Two lenses, lens #1 and #2, are used to connect the two optical fibers. Lens #1 can cause optical fiber A to produce a light with a object lens, which is changed into a parallel light, while lens #2 can use the parallel light to focus fiber optical B. From this, lens #1 and #2 can connect optical fiber A to optical fiber B. This method is different from the traditional butt connection, which is a contact type. In addition, FSOIs permits alignment errors, which is helpful to users. The entire CIO is comprised of three connectors, including the O/E conversion part, the Receptacle Lens (Re. Lens), and the Plug Lens.

The O/E part is mainly used to connect the O/E Module and optical connectors. The optical fiber can be directly inserted in the O/E part, and as the front end has four apertures, and bare optical fiber end face is flush with the four apertures. The light of the Tx Port on the module is focused and coupled via the micro lens on the O/E Module, and the light received from the optical fiber can collimate the O/E Module through the micro lens. The front end has four plano-convex lenses for collimation of the diffused light from the optical fiber end. The Re. Lens has a set of alignment pins for the alignment and butting connection with the Plug Lens. The Plug Lens and Re. Lens have the same number of lens sets, which forms a free space connection. In addition, the Plug Lens has a pair of positioning apertures connecting with the Re. Lens positioning apertures in order to maintain the optical fibers at both sides, and the lens, in the same optic axis.

It can be seen that the lens plays an important role in optical transmission as they can improve optical connection quality and coupling efficiency. Thus, many studies have discussed lens inspection, including probe measurement, 3D measurement, optical

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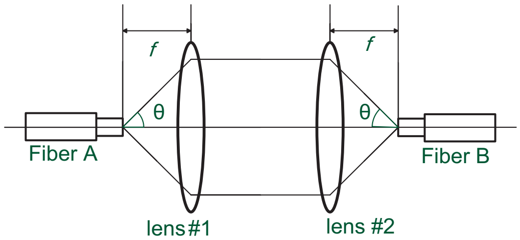

Fig. 1. Free Space Optical Interconnects (FSOIs).

measurement, and confocal microscopy measurement. To reduce damages due to contact with lens, the lens inspection focuses on optical measurement [1–5]. In addition, there are studies on optical lens imaging analysis and inspection [6] and positioning inspection [7].

The fuzzy theory is a common image processing method, which is often used for image noise analysis, and comparisons between enhancement and edge analysis [8–12]. Scholars have used non-linear filters for identifying color and noisy edges [13], thus, studies combining image processing with fuzzy theory and neural systems are mature [14–16]. To achieve precision below the pixel, studies on sub-pixels [17–19] have been conducted. For example, a measurement method using subpixel localization with color gratings and picture-in-picture switching on a single display can obtain 1–3 mm accuracy [20].

In this paper, a new fuzzy ratio analysis method is presented for inspection of optical connectors to ensure component quality and the stability of coupling efficiency. The system architecture consists of a CCD and lens sets, a backlight module, and image capturing and processing device. The light source is a blue backlight module. In addition, other devices include a FUHO FUM-630 Color CCD camera, a 2X Adapter, a Navitar Manual Zoomlens, a Tamron 1: 3.9 adjustable object lens, and an M PLAN APO LENS 20X. Fig. 2 shows the system architecture diagram and entity architecture diagram.

2. Algorithm and system design

2.1. Edge determination

During identification of an image edges, identification of circular edges is more complex than a straight line edge. The straight line edge is clear, while the circular edge often has low contrast, and fuzzy zones can occur. The edge cannot be accurately identified due to the fuzzy situations of the edge zone.

As shown in Fig. 3, the sharpness of the circular edge is different from that of straight line edge. Thus, this experiment used a new fuzzy ratio analysis method to identify edge position. In this fuzzy theory, the experiment employed image gradient as system input, as edges often have high gradient values. However, high gradient value does not denote the edge, as the image often contains sudden bright or dark points, resulting in a high gradient value of the point.

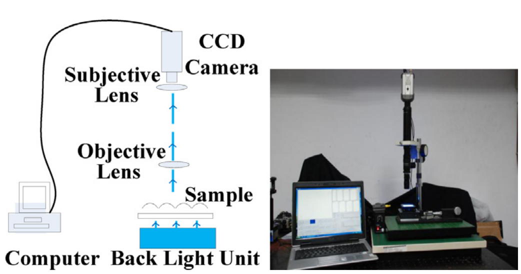

Fig. 2. The architecture diagram and photo of the automatic optical inspection system for optical connector.

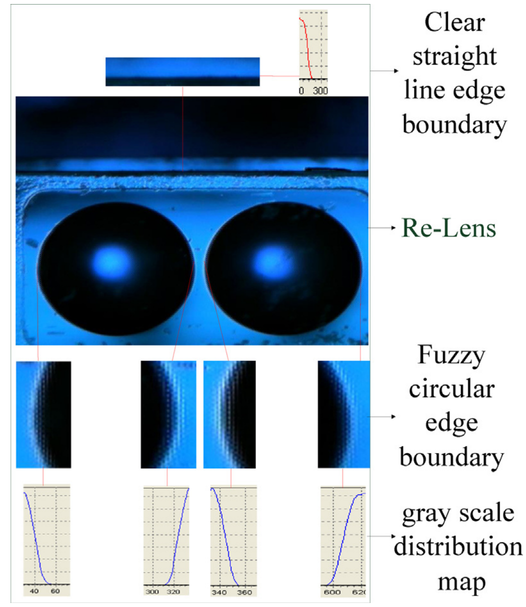

Fig. 3. Fuzzy circular edge and straight line edge of an optical connector.

To avoid this mistake, this study selected the gray scale value of the image as an input physical quantity. The membership function of two inputs can use the corrected edge point from the 110 μm micro lens as reference.

After selection of the detection range, the gradient values of all pixel points in the range are calculated. The membership function corresponding to the gradient fuzzy set can be calculated according to the gradient value. The fuzzy functions of the gradient value are $L_d(u)$, $\Pi_d(u)$, and $\Gamma_d(u)$, where u represents the gradient value. The description is as follows:

In the defined gradient fuzzy set, fuzzy set $L_d(u)$ belongs to the pixel point with the smaller gradient value, and the point has a low possibility of serving as the edge.

$$L_d(u) = \begin{cases} 1, & u < 10 \\ 1 - \dfrac{u-10}{30-10}, & 10 \le u \le 30 \\ 0, & u > 30 \end{cases} \tag{1}$$

Next, the gradient fuzzy set $\Pi_d(u)$belongs to the pixel point with a medium gradient value, where the gradient value range is 30–60. The image edge gradient value is within the range, and the point has a high possibility of serving as the edge.

$$\Pi_d(u) = \begin{cases} 0, & u < 20 \\ \dfrac{u-20}{30-20}, & 20 \le u < 30 \\ 1, & 30 \le u \le 60 \\ 1 - \dfrac{60-u}{70-60}, & 60 < u \le 70 \\ 0, & u > 70 \end{cases} \tag{2}$$

The gradient fuzzy set $\Gamma_d(u)$ belongs to the pixel point with a higher gradient value, and as a sudden bright point or dark point may cause a high gradient value, the point has low possibility of serving as the edge.

$$\Gamma_d(u) = \begin{cases} 0, & u < 60 \\ \dfrac{u-60}{80-60}, & 60 \le u \le 80 \\ 1, & u > 80 \end{cases} \tag{3}$$