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塑料眼镜内外缺陷检测的全内反射照明技术

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摘要:考虑目前大多数塑料眼镜镜片和光学表面的缺陷检测仍由人工完成,研究了基于全内反射照明的暗场检测技术,以提高用机器视觉进行自动缺陷检测的可见度及对比度,设计了镜头检测原型系统用于增强缺陷信号的强度并降低表面浮尘的干扰。利用设计的原型系统进行了试验测试并对自动缺陷检测结果与人工检测结果进行比较,结果验证了这种暗场全内反射检测技术的可行性。

关　键　词:塑料眼镜镜片;缺陷检测;机器视觉;全内反射
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TIR illumination technology for defect inspection of plastic ophthalmic lenses

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Abstract: Currently most plastic lenses and optical surfaces are still inspected directly by eyes by inspectors. In this paper, a Total Internal Reflection (TIR) illumination based dark-field inspection is analyzed and designed to enhance the visibility and contrast of the defects on the two surfaces of and inside the plastic lenses, and a lens inspection prototype is developed. Some trial testings have been conducted with the prototype, and the testing results are compared with those obtained from manual inspection directly operated by inspectors. The TIL dark-field inspection technique and feasibility to detect the popular defects of plastic ophthalmic lenses are verified and evaluated.

Key words: plastic ophthalmic lens; defect inspection; machine vision; Total Internal Reflection(TIR)

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1 Introduction

Nowadays plastic lenses[1] and other high precision surfaces, are still mostly checked by human eye. There are very few available in the market to replace visual inspection. For in-situ defect inspection of plastic ophthalmic lens, considering the range of possible defects and the locations, lens curvatures, contamination on the lens surfaces and also the cleanliness status, it is even more difficult to achieve automated machine inspection with comparable performance, such as rejection ratio, classification and speed. One of the key issues comes from the fact that in the bright field images, the contamination from the air of the environment is mixed with defects, and it is very difficult to distinguish them through image processing. In manual inspection, operators can easily check and verify the suspected by cleaning the corresponding area.

However, such manual inspections need a lot of manpower, which has been becoming more and more expensive. Moreover the results from manual inspection are subjective, and are therefore not uniform. There has been a lot of research work done in some research labs[2] and companies in to this automotive inspection area[3-5]. Among this research and development work, a special optical spatial filtering technology[2] is proposed and examined in a prototype, and some integrated technologies combining vision and image processing, and some combining laser scattering and statistics analysis[3-5] were proposed and investigated. But they could not used for in-situ testing, and therefore are difficult to evaluate objectively compared with manual visual inspection. Moreover, the inspection system based on normal bright and dark-field lighting all suffer from the same difficulty in distinguishing defects from dust. If an inspection machine ignores such an issue and is used under normal air-conditioning (in fact most lens and mirrors are manufactured in such condition) instead of high-class clean room, the image-based inspection result will treat the dust and contamination as defects, and give very high rejection rate and low yield. Such an in-situ inspection system will be difficult to use in real applications and receive acceptance from industry.

In the paper, a total internal reflection illumination technique is proposed to suppress the effect of dust and contamination on the lenses. TIR based optical defect inspection system is prototyped and investigated experimentally for detecting the typical defects inside the lens and on the two lens surfaces of the lenses, such as dots, scratches, lints, bubbles, cracks, inclusions etc. It is also evaluated and compared with manual visual inspection by an experienced inspector.

2 Analysis of contaminations and possible lighting techniques

Through studying the plastic injection process and analyzing the physical properties, the common features of defects and contaminations are as follows:

(1) They are both foreign particles /small objects on the plastic lenses;

(2) There is no significant difference in the physical features, such as possible size and shape;

(3) Both defects will scatter under normal dark-field lighting.

The different visibility under various illumination modes of these two particles will be addressed further in section III. For ease of analysis of the different scattering condition, we categorize the contamination into two types based on the distance to the physical surface of the lens:

(1)Type I: the contamination is floating on the lens surface; and its distance from the surface is greater than 200 nm (Type I Contamination).

(2) Type II: the contamination is stuck/ smeared/ in very close contact on the surfaces of plastic lens; and the distance from the surface is less than 200 nm (Type II Contamination).

There are many different illumination techniques for defect inspection. For the inspection of plastic lenses, the following three potential illumination techniques are described in detail:

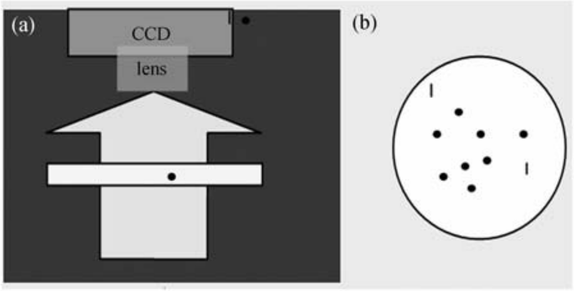
A. Bright-field lighting as shown in Fig. 1 has the features as follows;

* Direct illumination method, where the light source, image sensor (such as CCD) and the lens sample are placed in line;

* Images show as a bright background *vs.* dark defects;

* All contamination and defects are visible;

* The contrast and visibility of defects are relatively low.



(a) Sketch of the bright-field lighting configuration　(b) A typical image by CCD

Fig. 1　Schematic of bright-field lighting

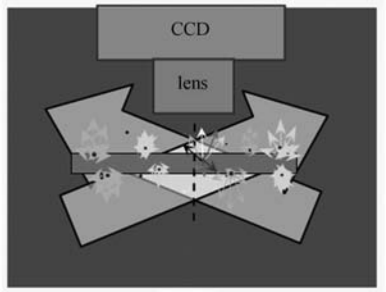
B. Oblique dark-field lighting has the following features, and its principle and mechanics are shown in Fig. 2;

* Dark background *vs.* bright defects;

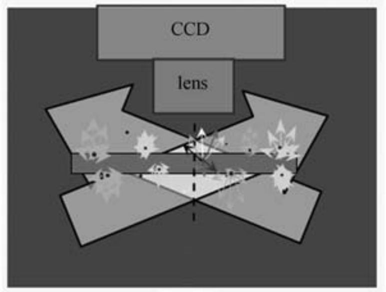
* Enhances all defects, as well as contamination;

* High sensitivity, but surface should be very clear;

* Popular for available glass and lens inspection systems.



(a) Sketch of the lighting configuration



(b) Its principle image

Fig. 2　Schematic of oblique dark-field lighting

C. Total Internal Reflection (TIR) based dark-field lighting as shown in Fig. 3 has the following features;

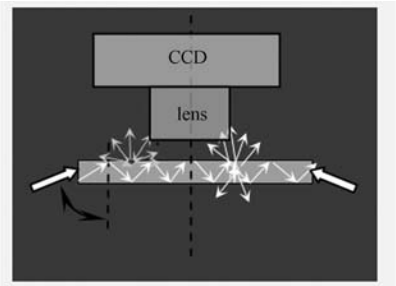
* Dark back ground *vs.* bright defects;

* Very high sensitivity for defects;

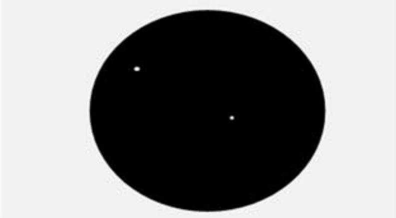
* Low sensitivity for contamination;

* Most contamination/dusts (Type I) are not illuminated;

* Only closely contacted (Type II) are lighted.



(a) Sketch of the lighting configuration



(b) A principle CCD image

Fig. 3　Schematic of TIR dark-field lighting

3 Analysis of scattering scenarios of a plastic lens

When inspectors observe the images of lenses obtained with machine vision technology, it is found that defects and contaminations are difficult to distinguish. In the image, they are very similar or even identical in many aspects.

A. Scattering scenarios under normal dark-field lighting

Scenario 1: The lens to be tested has no defects but has both types of contaminations. It is found that both types of contaminations scatter under normal dark-field lighting.

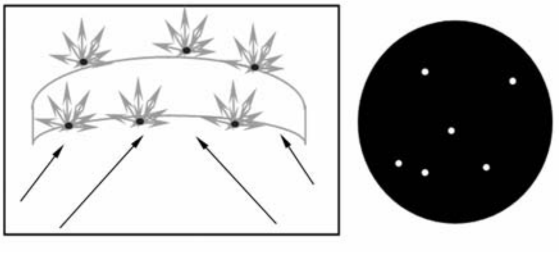


Fig. 4 Scattering mechanism (left) and principle image (right) of a lens with both types of contamination

Scenario 2: Lens with defects and both types of contamination

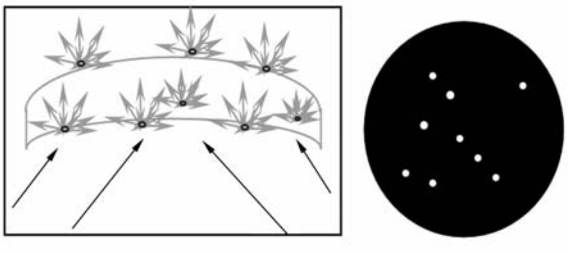


Fig. 5 Scattering mechanism (left) and principle image (right) of a lens with defects and both types of contamination under normal oblique dark-field lighting

As shown in Fig. 5, small particles-- defects and both types of contamination scatter under normal dark-field lighting, and can be seen in the image.

B. Scattering scenarios under TIR dark-field lighting

Scenario 1: There is no defects and no type II contamination with the lens, no scattering happens.

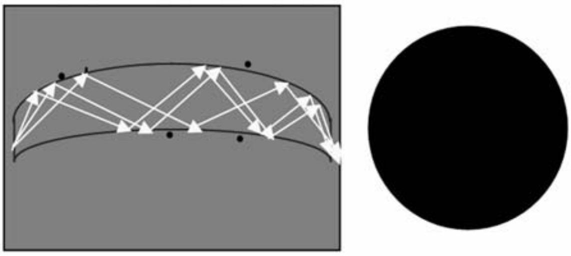


Fig. 6 Under TIR dark-field lighting the scattering mechanism (left) and principle image (right) of a lens without defects and without type II contamination

Scenario 2: some defects and no contamination,only defects scatter.

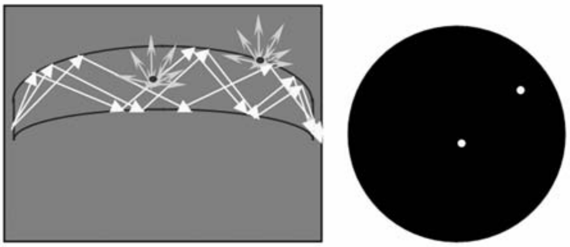


Fig. 7 Under TIR dark-field lighting the mechanism (left) and principle image (right) to be got by CCD for a lens with some defects and without contamination

Scenario 3: There are some defects and type I contamination in and on the lens. Only defects scatter light.

Most cases will be in scenario 2 and 3, especially under the following three conditions:

(1) the lenses have just been picked out from their moulds;

(2) the lenses have been cleaned;

(3) the factory environment is very clean.

Scenario 4: some defects and both type contamination.

Defects and Contamination II scatter.

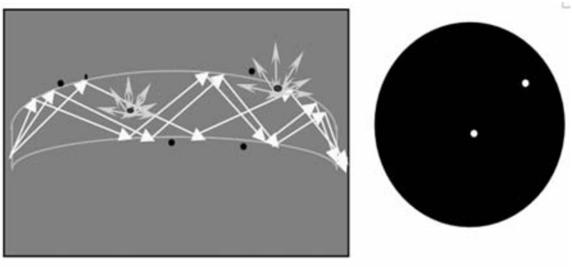


Fig. 8 Under TIR dark-field lighting the scattering mechanism (left) and principle image (right) for a lens with some defects and type I contamination

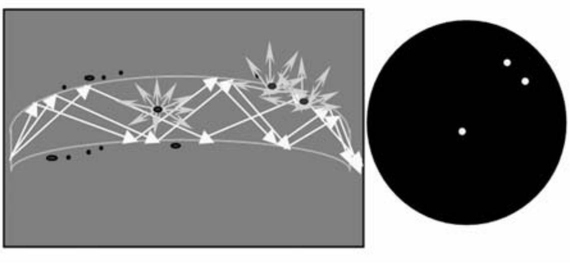


Fig. 9 Under TIR dark-field lighting the scattering mechanism (left) and principle image (right) for a lens with some defects and both types of contamination

Cleaning for Contamination II is necessary. Before have a complete cleaning, many real lenses such a scenario.

Scenario 5: many defects and both type contaminations

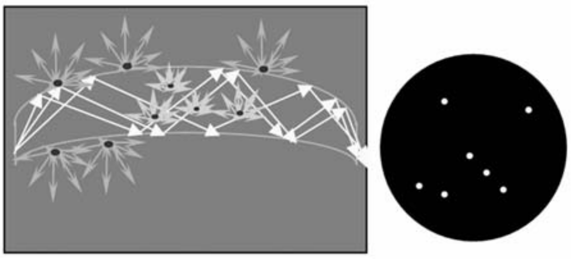


Fig. 10 Under TIR dark-field lighting the scattering mechanism (left) and image (right) are observed by CCD for a lens with many defects and left both types of contamination

Defects and contamination all scatter. It is because the scattering light from the defects lights up the Type I contamination. It is a very rare scenario. Cleaning for both types of contamination is necessary. This case happens only when there are many defects in a lens.

4 Analysis

From the detailed illustration of the possible scattering scenario of the plastic lenses, we can conclude that, for the most practical scenarios, TIR dark-field lighting obviously offers more advantages for defect detection, and the obtained images are less influenced by contamination. The pros and cons of different illumination techniques are summarized in Tab. 1.

Tab. 1 Comparison of three possible illumination techniques for defect inspection

Features	Direct bright-field lighting	Oblique dark-field lighting	TIR dark-field lighting
Image appearance	Bright back ground *vs.* gray/black defects	Dark back ground *vs.* bright defects	Dark back ground *vs.* bright defects
Image contrast	Relatively low	high	high
Sensitivity	low	high	high
Contamination to be detected	Big: easily Small: hard	All	Only Contamination II
Lighting efficiency	High	Medium	Low
Lighting Structure	Simple	Complicated	Complicated
Complexity	low	high	high

After analyzing and comparing these three lighting techniques, TIR dark-field illumination technique is adopted because it can reduce the influence of surface contamination to the image.

VI. TIR dark-field lighting system and prototype

Functionally, the inspection prototype consists of three systems as shown in Fig. 11: i) TIR dark-field lighting system; ii) a highly-sensitive machine vision system; iii) mechanical supporting system. TIR dark-field lighting system comprises a light source, light and sample-

Fig. 11 Lens defect inspection prototype

holding mechanics and a power supply as shown in Fig. 11.

In order to detect the defects located in various directions, a quadrangular light source is adopted to achieve quasi-uniform surrounding illumination. As shown in Fig. 12, from the lens edge the light is coupled into the lens in two directions perpendicular to each other and is reflected by and propagates within the two surfaces of the lens. Therefore a total internal reflection TIR mode dark-field illumination is generated. The lighting intensity of the light source is adjustable for inspection of different lenses.

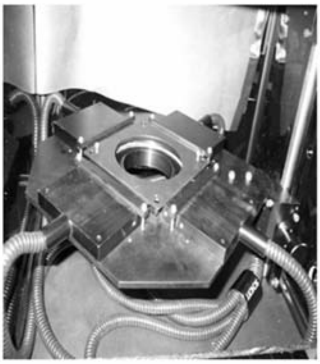
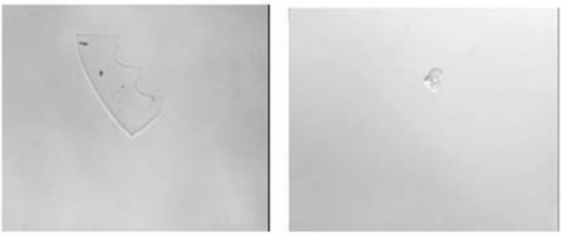


Fig. 12 Quadrangular TIR lighting system

5 Testing results and discussions

After several lab testing sessions and in-plant testing, we found that the developed TIR based inspection system can greatly enhance the detection of most (around 90%) defects, such as inclusions, lint, bubble, dots, scratch, stain etc, but is not sensitive to the smaller transparent inclusion defects (<0.25mm). Around 85% of results agree well with human inspection. The microscopy images of some defects are shown in Fig. 13. At the same time, the inspection prototype can offer high sensitivity and repeatability comparing with human eyes.



(a) A transparent defect around 1.4 mm in length inside －50° lens (b) Around 290 μm in size inside 375° lens

(c) Around 470 μm in length inside 500° lens d) Around 270 μm in 250° lens

Fig. 13 Microscope image of some transparent defects

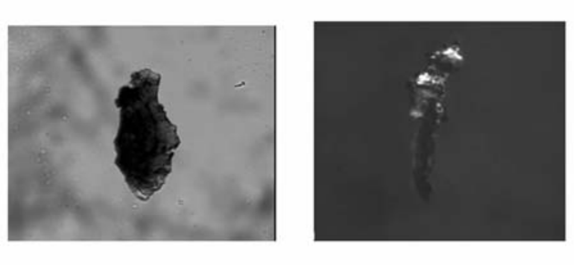
In detail, through the comparison testing we found that:

(1) Defects were obviously enhanced because of the dark background;

(2) Under reasonable cleaning (without Type II Contamination), all the defects can be more easily detected;

(3) Some special metal-like defects which were not found by inspectors were clearly checked by the developed TIR system. This means that those defects which were invisible to human eyes were pointed out by the system, and their existence was further proved with microscope images as shown in Fig. 14.

(4) Most contamination was not illuminated.



(a) Around 250 μm (b) Around 310 μm

(c) Around 290 μm (d) Around 170 μm

Fig. 14 Microscope (20X) image of some metal-like defects

We also found some important issues:

(1) Some large dust particles and contamination smeared on the surface (Type II contaminations) can be captured by the sensitive camera;

(2) It is possible to introduce some errors while estimating the size, location and shape only through a single 2D image. That is because a 2D image provides a top view of the defects only. A 3-D image or 2 2-D images can tell not only the size and shape of defects, but also can provide more information of the location and position of the defects, specially those narrow and/or thin, and directional defects, i. e. chips and scratches. So using one 3-D image or two 2-D images, one can estimate the size and location of 3D defects accurately.

(3) Cleaning attfects the results. Through two sets of testing in the clean room, the results showed that cleaning and contamination are a very important issue in the practical application of optical defect inspection of plastic lens. In a class 100 clean room, the developed system can detect 98% of those defects which were detected by an experienced visual inspection.

6 Conclusions

In the paper, TIR lighting technology for dark-field inspection of lens defects is investigated and developed, and an inspection prototype is built and assessed. By comparing the testing result obtained with the inspection prototype and inspected by a professional inspector, the results show that the lens inspection prototype without any image processing can detect 90% defects that are found by inspection. The current inspection system with TIR lighting can greatly enhance around 90% of defects, but it is not sensitive to small transparent defects with sizes less than 0. 25 mm. If the inspection is conducted in clean room, the inspection result will be better.

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●下期预告

双盘式渐开线测量仪基圆盘与导轨间滑移问题

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在双盘式渐开线测量仪中，基圆盘与导轨间的滑移是影响渐开线测量精度一个重要因素。有效控制轮轨间的摩擦力是解决基圆盘滑移的关键，本文分别采用传动绳与传动带对基圆盘滚动进行驱动，分析了在不同测量力情况下基圆盘与导轨间的摩擦力及对滑移的影响。通过分析与实验论证，当测量力为 0.7 N，采用传动绳驱动，当测量力为 0.2 N，采用传动带驱动，基圆盘顺时针转动测量渐开线时，轮轨间的摩擦力分别为 0.02 N 与 0.07 N，此时基圆盘滑移对渐开线测量影响可以忽略。通过增加基圆盘组件的配重，能够有效减小基圆盘滑移，此时基圆盘顺时针与逆时针转动测得的渐开线齿形的差异为 0.05 μm。