The Development and Prospect of Surface Defect Detection Based on Vision Measurement Method

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***Abstract*—Surface defects detection techniques are widely used and play very important roles in many fields, such as precision optical element used in high energy laser, wafer used in semiconductor, cover glass used in mobile phone, etc. This paper introduced the research progress in surface defect detection based on vision measurement, analyzed the significant and application of detecting the surface defect by using vision measurement, summarized the main work of this technology, and analyzed the key points and challenges in the application of these techniques. At last, this paper outlines the prospect and the direction for the surface defect detection based on vision measurement.**

I. Introduction

The quality of the product surface is very important to the appearance and performance of products. For example, optical element surface quality can severely affect the performance of optical system. But, during the process of manufacturing, product will inevitably produce some defects on its surface. For instance, the large aperture optical element used in ICF(Inertial Confinement Fusion), its surface may produce some defects like pits, scratches, dusts, fibers and stains , as shown in Fig. 1. As for cover glass of touch screen, it may produce some defects like scratches, chamfer, deformation, cracks, and chippings, as shown in Fig. 2.

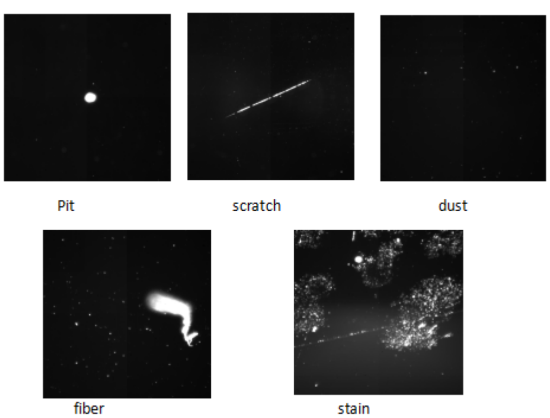


Fig. 1. typical defects on the optical element surface

And Fig. 3. shows the typical defects may be produced on float glass surface, like bubbles, concretions, bruises and scratches.

The surface defect are generally detected by the human eye. But this task is tiresome and can cause damage to eyes. Especially, this method lacks of sufficient efficiency and accuracy. Therefore, automatic surface defects inspection technology is becoming an important issue. In fact, vision measurement plays a crucial role in automatic inspection.

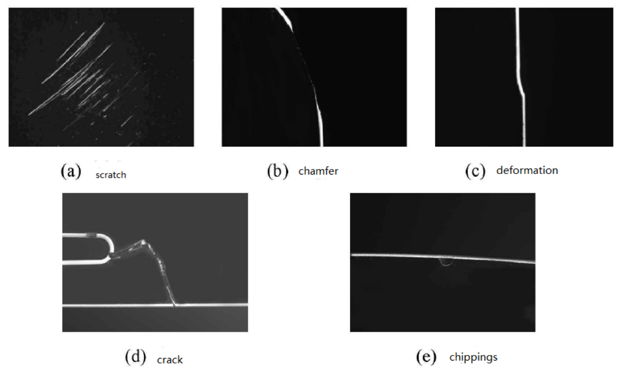


Fig. 2. typical defects on cover lens of touch screen

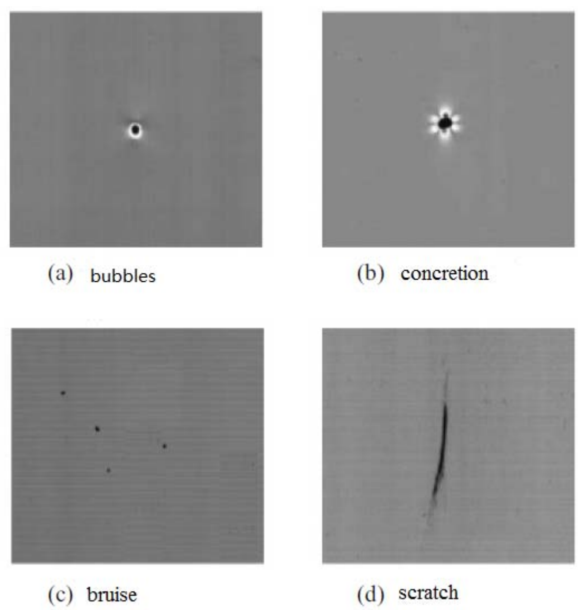


Fig. 3. typical defects on float glass surface

II. Application and Development

Currently, vision measurement is widely applied in surface defects detection. For instance, [1-3] presented a versatile and open automated visual transparent parts surface defects inspection system. This system can be adaptable to different products by adjusting the hardware and inspecting algorithms. However, the segmentation algorithms such as OTSU, Multistage adaptive and Rosin in the system can't be

This work was supported in part by National Natural Science Foundation of China under Grant 61473293, Youth Innovation Promotion Association CAS(2013097). All authors are with the Research Center of Precision Sensing and Control, Institute of Automation, Chinese Academy of Science, Beijing 100190 (Corresponding email:yuanlunxi14@mails.ucas.ac.cn)

adaptable to all transparent parts, which will affect its flexibility. As integrated circuit (IC) feature sizes shrink, semiconductor processes become more complex. In order to reduce the influence of the defects on wafer surface, [4] used a 8 millions resolution camera, adopted Image Subtraction method and normalized cross correlation method to detect the defects on wafer surface, which can achieve 97.3% accuracy rate. And its detection precision can be 15μm. Fig. 4. shows the hardware of this system. The hardware consists of CCD(charge-coupled device), Lens, Light source, Enclosed test chamber, Image capture card and PC. However, the inspection result can be easily affected by image noise and lens vibration.

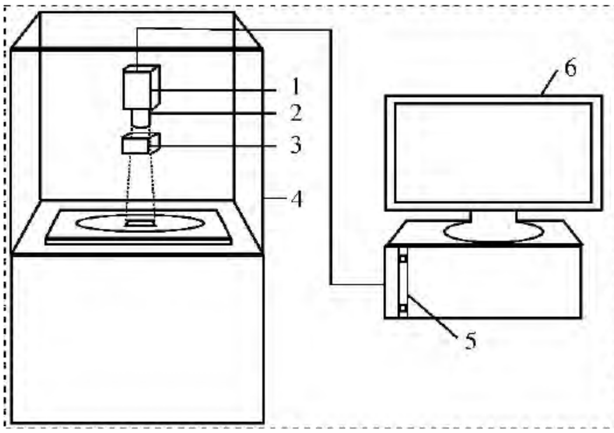


Fig. 4. the hardware of the inspection system

The large aperture optical element is the core component of many modern optical system like space telescope, astronomical telescope, National Ignition Facility Project (NIF) and ICF. For example, NIF may need above ten thousands optics, and the large optical element may be several thousands. Especially, the large aperture optical element not only need extremely high precision surface, but also is very expensive. Therefore, [5-9] researched the application of automatic vision inspection in the large aperture optical element surface defects.

[5] designed a microscopic scattering imaging system, just as shown in Fig. 5. The system consists of CCD, Multibeam fiber optics illuminator, XY-scanning system and so on. XY-scanning system moves the test optics to capture the whole surface image by image acquisition unit. Under high zoom condition, this system can detect 1μm even smaller defects on the optics surface. But it takes 1-2 hours to detect a size of 800mm*400mm optical element because of its low efficiency of software.

Defects on float glass surface will affect the appearance quality, transparency, mechanical strength and thermal stability, result in a lot of waste. To improve the quality and glass quality grading float glass, [10-11] studied how to inspect the glass surface defects online. The typical inspection system is as shown in Fig. 6. Back lights source is very suitable because of the difference in transparency between glass and defects, and high speed linear array CCD will be choose. [11] discussed the effect of match degree between the line frequency and the speed of float glass on the glass images,adopted double-DMA mode to transfer image data, which can achieve online inspection. And its defects recognition rate can be up to 99%. However, its defects inspection precision is only 0.1mm.

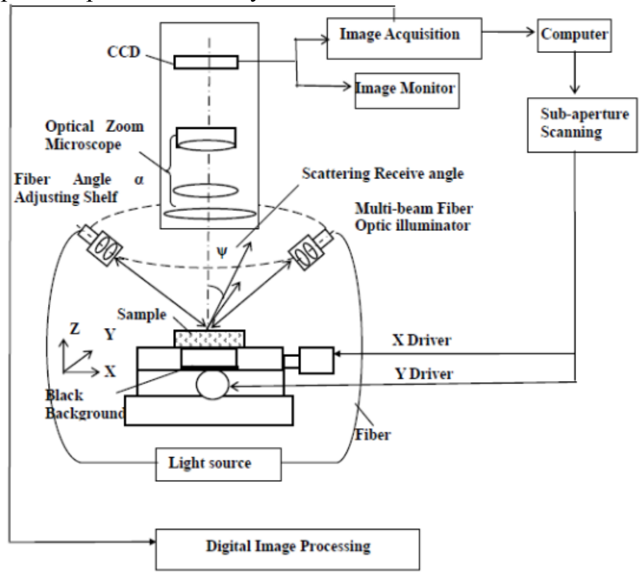


Fig. 5. Microscopic Scattering Imaging System

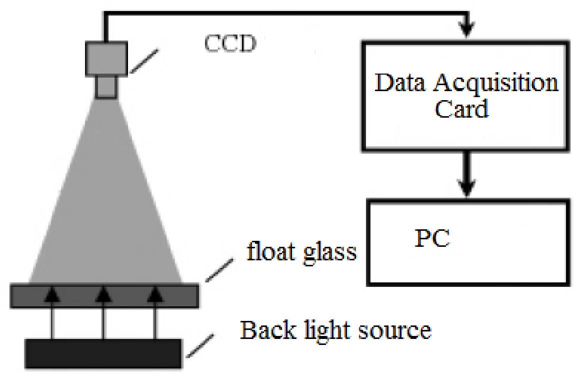


Fig. 6. typical inspection system

Resin lens is the key component of glasses.To improve its surface quality, [12-15] discussed how to inspect the surface of resin lens. Considering that it may take a worker 7-10s to inspect one resin lens, [13] proposed an online inspect system, just as shown in Fig. 7.

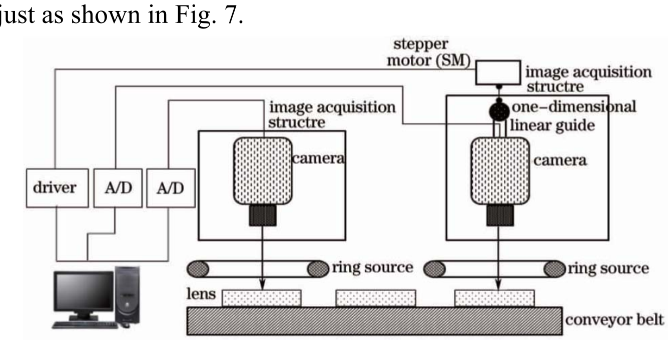
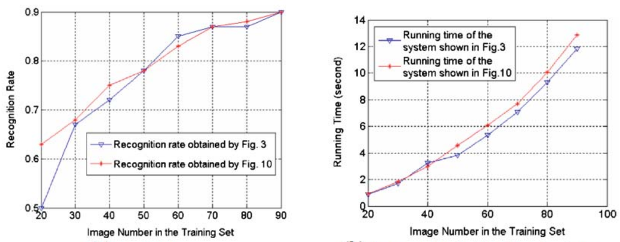


Fig. 7. Schematic diagram of the system

The system adopts two image acquisition structure to improve the acquisition speed, and thus improving the image processing speed. Finally, the whole time that inspect a lens is 1.5s, which is totally faster than human eye inspection.

In order to achieve automatic surface defects inspection of touch screen, [16-18] researched this technology on different parts of touch screen. [16-17] focus on the cover glass of touch screen, and [18] pays more attention to transistor-liquid crystal display of touch screen. As for cover glass, [16] proposed a surface defects detection system.The system adopt principal components analysis (PCA) algorithm to extraction features of surface defects. By comparing with features in the training set, select the most similar defect in the training set as the detection result. And Fig. 8. shows its recognition rate and running time.



(a) Recognition rate (b) Average running time for each set of test images

Fig. 8. Recognition rate and running time

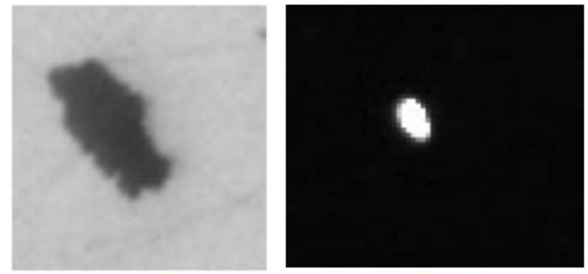
Besides applied in above products,the surface defects detection based on vision measurement technology can also be used in cold roll strips [19], strip steel [20], steel ball [21], textile fabrics [22], finishing [23], bearing [24-26] and aircraft skin [27].

For some products like cold strip ,thin plastic film, press work and Printed Circuit Broad (PCB), there are many matured defect detection equipment in market. For example, LUSTER LightTech company of China developed EAGLE inspection system, which can specially detect the defects on PCB surface. ISRA vision company of German developed SMASH surface inspection system, which can stably detect the defects on thin plastic film. MVC company of China developed an press work surface defects inspection system. Smart View system, developed by COGNEX company of USA, can inspect metal surface defects. However, all these equipment are very expensive. It is still well worth researching inspecting technology based on vision measurement in these field.

III. KEY TECHNIQUES

A. Imaging System

There are two main imaging system: Bright Field Imaging System(BFIS) and Dark Field Imaging System(DFIS). In BFIS, the defects will scatter the incident light into any direction, which result in only a few light come into the camera, but the background will be opposite. Thus the defects image dim in a bright background under BFIS condition, just as shown in Fig. 9(a). In DFIS, light source generally illuminate the product surface at a certain angle from the top side. And the incident light will be scattered into the camera by defects, but the background will not. Thus, the defects image bright in a dark background under DFIS condition, just as shown in Fig. 9(b).



(a) dust in BFIS (b) dust in DFIS

Fig. 9. dust in BFIS and DFIS

B. Lighting Technology

The lighting way of light source can obviously influence the quality of surface defect image. According to the different lighting way, light source can be divided into the following several common kinds: Ring light source, strip light source, back light source, and coaxial light source. Ring light source generally places over product directly and is used to highlight the edge and texture of product surface. Strip light source generally places above the product side in pairs. Back light source is suitable for highlighting the contour of opaque objects and measuring product size. Coaxial light source is appropriate for detecting defects on high reflective surface.

In addition, [28-30] deeply studied how the type of light source, lighting way and light source color affect the imaging system of machine vision, and discussed some crucial issues of light source such as efficiency and size of light source in detail. [31] analyzed how the location relationship between the light source and the camera affects defect image quality with the two kinds of cracks on float glass surface.

As regards to the spherical optical element surface defect detection, [32] analyzed how the relationship among angle of the illumination, light intensity and curvature radius of the spherical optical element influence the contrast of defect image . when the light incident angle α is 30 degrees, the surface defect image of spherical optical element can get the top quality. Moreover, this paper studied the relationship among the depth of field d, radius of field H and the curvature radius of spherical optical element R, which the system could detect. The relation is given in (1).

$$R = (d^2 + H^2) / 2d \tag{1}$$

[33] used a curved mirrors,which can produce slight deformation, to adjust the lighting angle. its illumination system structure is shown in Fig. 10. The system can detect irregularities hemispherical scratches on different curvatures product surface, whose average diameter can be up to 0.1-0.2mm.

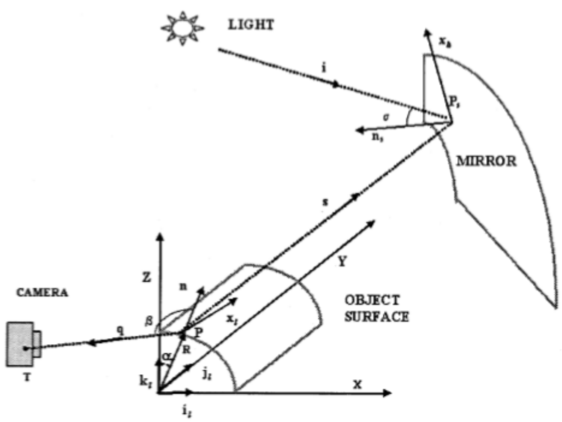


Fig. 10. illumination system structure

[5] studied the relation of the angle of v-scratch β (scratch falling edge with the horizontal angle is β) and the incident angle of lighting α, which can observably affect the scratch image quality, as shown in Fig. 11. When scratches scattered the incident light back to CCD, that is, when the incident light illuminates the scratches by angle β, the scratches get the high contrast image. When the incident angle is smaller than β, scratches image contrast decline, when the incident angle is greater than β, scratches image is weak or even not visible.

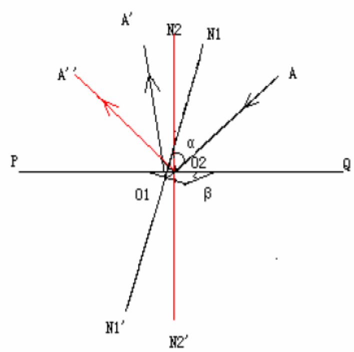


Fig. 11. light direction and scattering angle

According to this theory, by adopting a multibeam light sources, the CCD can capture images of different directions scratches, which effectively improved the quality of scratches image. This system is capable of detecting 1μm or smaller scratches.

C. Surface Defect Feature Extraction Method

Due to random distribution, different shape and different direction of surface defects, defects extraction and classification become a bottleneck of surface defect detection based on vision measurement technology. Therefore, many researchers made much effort in this field.

For some product with high contrast and simple background surface defect images, such as glass fiber fabric [34], semiconductor molding surface [35], and wafer [36]. it generally extracts their surface defects by Image Subtraction processing and Blob analysis algorithms. Blob analysis algorithm is adapt in extracting defects like digs, dusts, and bubbles on the surface of the product.

For the weak scratches feature extraction in image plane, [37] proposed dual-threshold algorithms based on the filter and difference method. By far, the algorithm has been applied to the large aperture optical element surface defect detection system in ICF, and the detection accuracy is about 80%. As for intermittent weak scratches, [38] proposed an improved Random Hough Transform method, which can effectively connect intermittent weak scratches.

In order to extract surface defects in low resolution or low contrast images, [39] proposed a effectively method based on sparse representation in low resolution images to inspect defects on touch screen surface. [40] proposed a twice OTSU segmentation method with 3σ criterion to locate the valid region of glass defects in the image pre-processing course in low contrast images.

D. Flaw Classification and Recognition

Currently, researchers usually adopt machine learning method such as Bayesian, KNN, Cluster algorithms, SVM,BP neural networks to classify and identify surface defects.

For instance, as to float glass surface defects detection, [41] extracted 12 statistical features like pitch angle, eccentricity, ratio of length to width, extension degree, fill factor, edge flatness, horizontal evenness, vertical evenness, vergence, connectivity leading rate, gray standard deviation, percentage of up-gray pixels, then classified and identified the surface defects by BP Neural network classifier . Under 85 samples of various types defects, the method can identify overall 85% defects.

[42] studied the classification of three defects on the glass lens surface. Classified the defects by extracting roundness and line fitting correlation coefficient as the features of defect, its recognition rate can be above 90%.

In [40], four classifiers of artificial neural network (ANN) and fuzzy k-nearest neighbor (FKNN) are designed to categorize the glass defects. The identification results are made by fusing the decisions from four classifiers with an improved Dempster-Shafer (DS) evidence theory, which can evidently improve the recognition rate of surface defects on float glass than single method. However, this method still make confusion decision on cracks.

Due to similarity in shape, a method that based on Bayesian principles was proposed to classify dusts and digs on large optical element surface in [43]. The result shows that the accuracy is above 95%. This method has been used in the ICF yet.

For mobile phone cover glass surface defects, [16] adopt principal components analysis (PCA) algorithm to extraction feature of surface defects. by comparing the features with that in the training set, select the most similar defect in the training as the detection result. The defect recognition rate of the method is over 90%.

For damage on aircraft skin surface (cracks, corrosion and impact, etc.), in [44], Fuzzy Support Vector Machine (FSVM) based on sample affinity method has been used to classify the damages,which is superior to the SVM. And FSVM can achieve a 93. 3% recognition rate.

E. Defect Measurement and Digital Evaluation

Defect size is an important attribute of the defect, and therefore in the product surface defect detection, the defect size measuring is full of practical significance. In [45], the approximate mathematical relation between viewing dimension y and real dimension x of large aperture optics surface defects was studied, just as given in (2). However this relation is only succeed in some range.

$$y \approx 3.6x + 0.29 \quad (2)$$

[46] researched on accurate measurement about the depth of the aircraft cockpit and wing skin surface scratches. The relation among scratches depth L, camera pixel size p, the pixels number of scratch n , and optical zoom of N is shown in (3).

$$\mathrm{L} = \mathrm{Np}/n \quad (3)$$

For some high diffuse reflective metal surface, due to the relatively fuzzy edge of surface scratches, this paper put forward a single point measurement approach to calculate the depth of the scratch; As to high reflective product surface like glass, because of clearer outline, this paper proposed multipoint fitting method; and for relatively standard scratches, linear fitting method can be adopted. The problem of measuring the depth of v-scratch is effectively solved in this paper.

[47] designed a large aperture optical element surface defect detection system, with BFIS and DFIS. Due to the size of the smallest defects under the dark-field conditions that the system can detect is much smaller than the size in the same system under bright field conditions [48]. This method obtained the defect position under DFIS, and then measured the size of defects using BFIS. Its inspection precision can reach 3μm. This method has significantly improved the detection accuracy.

Based on minimum enclosing rectangle(MER) algorithm, [49] proposed a size measurement method suitable for many types of scratch, which can not only measure the linear scratches, but also for bending scratches.

Digitized evaluation of surface defects has a very practical significance. It usually evaluates the product surface quality based on the number, sizes and types of defects on the product surface. Based on the fuzzy evaluation judgment method, [50] uses the analytic hierarchy process to evaluate the surface quality. Through accurate measurement of the length and width of a scratch, [51-52] realized the digital evaluation of surface scratches. In order to solve the difficulties of digitally evaluating surface defects of optics by American military standards MIL-PRF-13830B, [53] raised a kind of judgment algorithm of surface defects concentration based on the method of overlap of weight region. This make the digital evaluation more international.

IV. Prospect of Surface Defects Detection Based on Machine Vision

During the surface defect detection process, since the defects are randomly distributed on the surface of product, and its shape and direction are not fixed, how to get high contrast defects image has always been a difficulty in surface defects detection system. while light source structure determines the quality of defects images. Just as described in [5], how the relationship between the incident light angle and the v-scratch angle affect scratches image quality, but this method is only suitable for v-scratch. Therefore, design a light source structure which can obtain high quality of defects image will be a direction of researching surface defects detection based on machine vision technology.

Currently, researchers usually adopt machine learning method such as Bayesian, KNN, Cluster algorithms, SVM,BP neural networks to classify and identify surface defects. However, there is still a long way to achieve the same results made by skilled worker in surface defects classification and recognition. How to improve the recognition rate of surface defects has been a bottleneck of surface defects detection based on machine vision. Therefore find a new classification and recognition method is one direction of surface defects detection technology, such as deep learning.

V. Conclusion

This paper introduced the research progress in surface defect detection based on vision measurement, analyzed the significant and application of detecting the surface defect by using vision measurement technology, summarized the main work of this technology, and analyzed the key techniques and challenges in the application of these techniques. At last, this paper outlines the prospect and the direction for the surface defect detection based on vision measurement method.

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