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Development of an Automated Optical Inspection System for Mobile Phone Panels

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Keywords： Mobile phone panel, Automated optical inspection, surface defects, film thickness.

ABSTRACT

Smart mobile phone is the most popular consumer product nowadays. The quality of the mobile phone panel is important as it gives the first image to potential buyers. Many mobile phone glass panels have the black thin film coating surround the boundary. Some surface defects and uneven coating thickness will degrade the appearance quality of the mobile phone. This research aims to develop a multi-function automated optical inspection system for the mobile phone panels in the production line.

Different from some commercial systems that can only identify the 2D surface defects or the 3D film thickness, the developed system is capable of detecting both the 2D defects on the whole panel and the uniformity of 3D film thickness of the glass coating. The 2D surface defects are inspected by the image processing system that can not only extract the defects through the technique of pattern recognition but also classify the defect types by the technique of morphology. The film thickness is measured by a focusing probe utilizing the DVD pickup head as a low cost sensor.

Experimental results show that five types of surface defects, including the hole, oil stain, scratch, stripe and edge, can be classified with 100% success rate. The focus probe processed by normalized focus error signal (NFES) technique can achieve both the measurement accuracy and standard deviation less than 0.1 μm.

INTRODUCTION

In recent years, automated optical inspection (AOI) technology has been widely used in many industries for defect inspection and classification, such as PCB, TFT-LCD, etc. The AOI system rapidly scans the object to store continuous images into the processing system and, then, identify and classify various types of defects with proper algorithms. Many hi-tech industries urgently need AOI equipment to control the process quality at each stage, such as the PCB industry (Moganti et al, 1996), TFT-LCD industry, IC industry, solar cell industry, mobile phone industry, etc. to replace labor-intensive manual inspection jobs (Fan et al, 2005).

There are net al.umerous methods and mathematical algorithms in the area of AOI technology nowadays. Moganti et al. divided processing methods into three main types: reference-based, rule-based and hybrid-based (Moganti et al, 1996). According to Sanz and Jain (1986), the defect inspection of PCB is mostly known by the referential-based method. The captured image is compared with a non-defect reference image that stores in the data base to detect a designated region of inspection (ROI). The image comparison algorithms use simple XOR logic operator to detect the defects. Akiyarnai et al. (1983) developed the PCB defect detection method by referential template matching. The templates were compared with the inspected image to detect the large defects in the first place. They then used a logical AND operation for all sizes of defects to extract defect image. Huang et al. (2008) developed an automated visual inspection system for detecting and classifying defects of a micro-drill. The detection algorithm was based on the geometric relationship of the edge points in the ROI. The reference-base method needs alignment mark and precision moving mechanism to provide a stable image location for matching the pattern. The rule-based method needs to designate the object pattern and the ROI of image. It is difficult to change to the different sizes. The hybrid-based method combines the merits of the reference-based and the rule-based methods to compensate for the shortcomings of each method. The author's group has successfully developed a hybrid-based method to classify the defects on powder metallurgy parts (Fan et al, 2010).

The image processing algorithm is a key to the AOI systems. There are many basic theories, such

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as auto threshold selection, edge detection, noise reduction, mask convolution, etc. It is generally called image pre-processing, which can be used to remove unwanted noises and enhance some important image features for further image processing.

Facing the rapid development of communication technology in recent years, almost everyone carries a mobile phone in today's society. New model innovation at short lifetime cycle and extremely huge volume production are becoming very competitive in the market. In such a large volume of production process, quality control of products will require a stable and fast automatic inspection system to, for instance, the protection layer of the panel surface, which gives the first appearance image to the buyers, to improve the product quality. Many mobile phone glass panels have thin film coating around the display window. The surface quality of the mobile phone panel normally involves two different aspects, namely the 2D quality for various defects and the 3D quality for uniform film thickness. Current commercial AOI equipment systems usually can detect only one kind of quality.

Based on the industry's emerging and fast quality inspection demand, this study aims to develop a versatile detection system for mobile phone panel. Different from the standard inspection system which can only identify surface defects or film thickness, the present system is capable to detect both the 2D defects on the whole panel and the uniformity of 3D film thickness of the glass coating simultaneously.

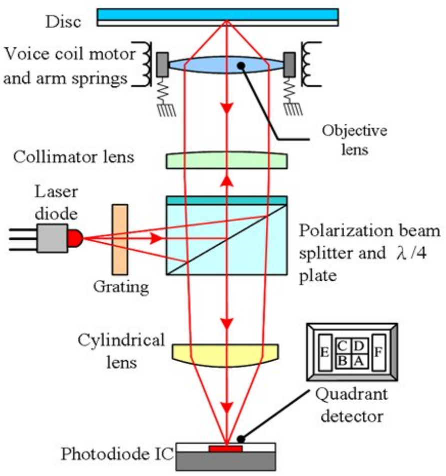


Fig. 1. Optical structure of a DVD pickup head.

PANEL THICKNESS MEASUREMENT

The principle of DVD pickup head

The DVD pickup head is used to detect the stored binary signals on the DVD track with the focused laser spot based on the astigmatic principle. Fig. 1 shows the optical system of a commercial DVD pickup head. The laser diode emits a beam through the grating. The beam then splits into three beams that pass through the polarization beam splitter, the quarter wavelength plate, the collimator lens, the objective lens, and finally focus onto the disc surface. The reflected beam passes through the same original path and, after two polarizations by the quarter wavelength plate, projects onto the quadrant detector through the cylindrical lens. The photodiode outputs focus error signals (FESs) based on the astigmatic principle, as expressed by Eq. (1).

$$FES = (V_A + V_C) - (V_B + V_D) \qquad (1)$$

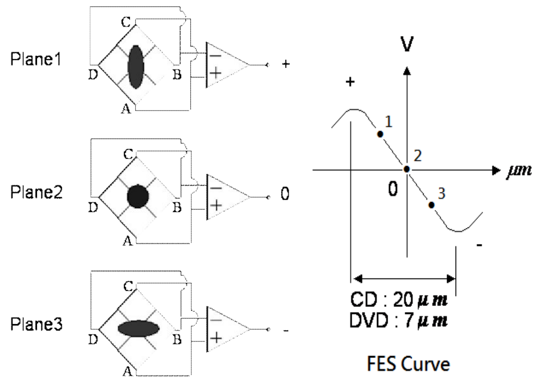


Fig. 2. Schematic diagram of astigmatic method

If the measurement surface is near to or far away from the focal point, the image of the beam on the photodiode becomes elliptically shaped in different orientations (Fig. 2, plane1 and plane3). If the measured surface is in focus, the image becomes circular (Fig. 2, plane2). According to the beam spot distribution among the four quadrants, the FES is used to measure the profile of the disc after calibration. A voice coil motor is used to trace the flight height change of the rotating disc. This focus or auto-focus probe technique has been developed over the course of more than ten years by the author's group (Fan et al, 2000, 2001). The FES is processed by a differential circuit. Its linearity range is about 7 μm for a DVD and 20 μm for a CD, corresponding to 0.65 numerical aperture (N.A.) of the pickup's objective lens.

It is known that the reflected light intensity is sensitive to the color of the reflecting surface. The coating on the mobile phone panel is normally in black color, which significantly reduces the intensity of reflected light. Therefore, a normalized technique on the FES signal, called NFES, is necessary to be employed, as expressed by Eq. (2), so that the influence of surface reflectivity can be eliminated.

$$NFES = [(A+C)-(B+D)]/(A+B+C+D) \qquad (2)$$

Design of the measurement system

The structure of the developed probe system is shown in Fig. 3. The original objective lens and voice coil motor of the DVD pickup head (Hitachi HOP-1000) are removed. A new microscope objective lens from NIKON (20×, N.A. 0.4) is attached in order to increase the linearity range of the FES to about 20 μm. A CCD camera can assist the user in viewing the exact measured point on the surface. It is also used for defect inspection, which will be expressed in Sec. 3.

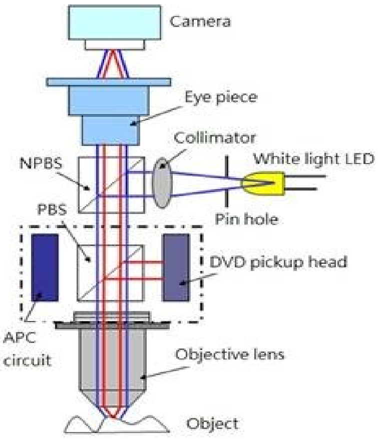


Fig. 3. The measurement system

Thickness measurement results

Fig. 4 shows the measured four locations of the coated film on the panel. Fig. 5 plots the calibrated NFES curve together with the total intensity (SUM) received by the quadrant detector.

Fig. 4. Locations of film thickness measurement

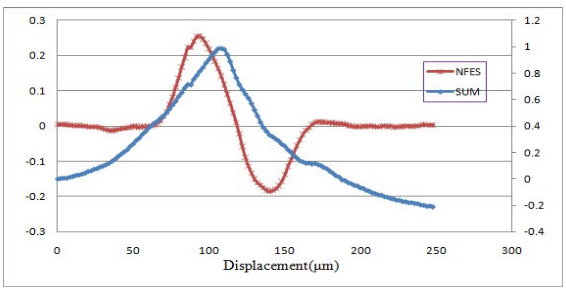


Fig. 5. The NFES of coating area

The linearity range is about 20 μm. The measured film thickness at four corners is about 8μm in average with resolution to 0.01 μm, and standard deviation is less than 0.1 μm, as listed in Table I.

TABLE I

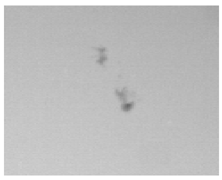
FILM THICKNESS MEASUREMENT RESULTS (UNIT IN μm)

Position	A	B	C	D
1st	8.03	8.21	8.31	8.22
2nd	7.93	8.10	8.33	8.28
3rd	7.77	8.23	8.40	8.45
4th	7.95	8.34	8.34	8.31
5th	7.93	8.33	8.49	8.42
Mean	7.82	8.24	8.37	8.33
σ	0.09	0.10	0.07	0.09

THE 2D DEFECTS INSPECTION SYSTEM

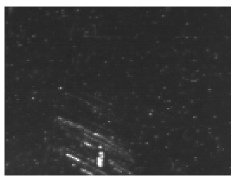
Defect types

The defects will occur in two regions on the panel, including the glass window area and the surrounding black coating area. According to the expert's rules of the manufacturers, there are three typical defects on the coating area, namely the scratch, hole, and imperfect edge, and two types of defects on the glass window, i.e. oil stain and stripe. The size of these defects is varied from several millimeters to tens of micrometers. In order to enhance these fine defects in the imaging system, both the front lighting and back lighting are used. The back lighting image can clearly identify the holes in the coating area, while the front light image can recognize the remaining defects. Fig. 6 shows the images of these five typical defects captured by proper lightings and image processing techniques.

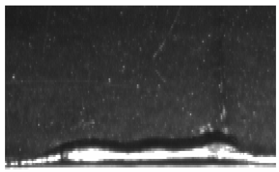


(a) Oil stains

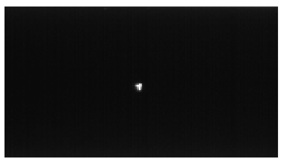
(b) Stripes



(c) Scratches



(d) Imperfect edges



(e) Holes

Fig. 6. 5 types of defects of the mobile phone panel

Measurement system

This study aims to integrate the defect inspection system into the film thickness measurement system as a multi-function AOI system, as described in Fig. 3. The LED light source provides the front projection lighting. A transparent surface of XY table is employed to move the inspected panel to different locations and then the panel image is reflected and captured by the CCD camera of 1280× 1024 pixels. A back lighting is added at the bottom of the moving table so as to transmit the panel image to the CCD for detecting the defect of hole in coating area. The image processing software is developed with Borland C++ Builder 6.0 in the form of a library so that proper pre-processing tools, such as filtering, binarization, edge detection, etc. can be assembled for use. In addition, morphological algorithm can be added for defect classification, which will be expressed in Sec. 4.

Detection process

Without any defect, the image is pure black or white with respect to the coating or glass area. Therefore, two standard templates in black and white colors are stored as references. Since the defects are as fine as tens of micrometers, the field of view has to be small enough. The XY table was set to incremental step of 0.4 mm. At each position, the image is captured by the CCD camera.

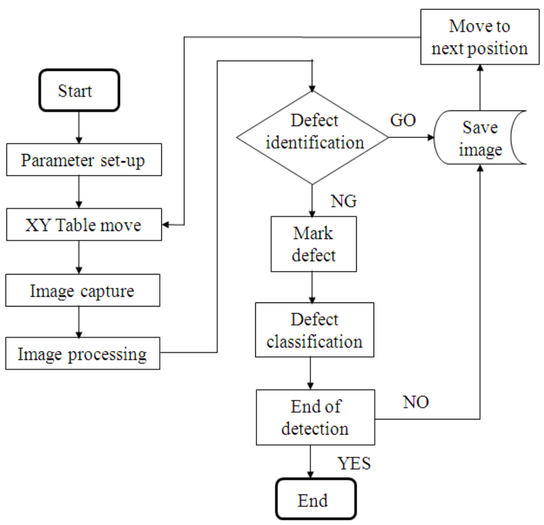


Fig. 7. Flow chart of defect inspection

The image processing technique is used to enhance the required signals from captured image. The techniques we used are: (1) binarization with a given threshold value of the gray level to identify defect points (Otsu, 1979), (2) spatial convolution with Gaussian filtering to remove salt and pepper noise and (3) edge detection with Canny method (Canny, 1986). After pre-processing the image is compared with the template according to the location in black or white region. If there is no defect found, the stage moves to the next position. Detected defects were marked by an enclosing rectangular window for classification, which will be described in the next section. This process was iterated to the end of total scanned area. The flow chart is depicted in Fig. 7.

SURFACE DEFECT INSPECTION

Defect feature extraction and classification

The morphological Open/Close and 8-connected operations were applied to mark the defect blob. A rectangular window was automatically generated to exactly enclose each defect area. The rule-based morphological algorithm was proposed to identify different types of defects according to the defect size and its aspect ratio of the marked window. The size of defect was counted by the corresponding pixel numbers (unit: PN), while the aspect ratio was calculated by the long to short size ratio (unit AR) of the rectangular window.

As expressed in section III-A, the types of defects are specified by the quality engineers of the mobile phone manufacturer. This is what we called "expert's rule' in this study. The defect of oil stain is occurred during coating that a small paint is splashed onto the glass window resulting in a small gray area on the transparent glass. The PN and the AR are all small. The defect of stripe appears irregular lines on the glass window. It could be due to accidental scratches during manufacturing. Its PN is relatively small while AR is large. The defect of scratch is defined in the coating area appears similar shape as the stripe. The scratch is, however, more serious than the stripe. The defect of imperfect edge is more obvious on the coating area due to insufficient coating. Its PN and AR are all relatively large. Table II summarizes the classification rule of each specified defect used in this study. The defect of hole occurred only at coating area and with back lighting. It could be easily sorted out.

TABLE II.
Classification rule of each defect type

Lighting	Zone	Rule	Defect
Front	Glass	40≦PN≦70 2≦AR≦4	Oil stain
		19≦PN≦35 3≦AR≦20	Stripe
	Coating	50≦PN≦230 4≦AR≦15	Scratch
		1000≦PN≦3000 13≦AR≦25	Imperfect edge
Back	Coating	Small spot	Hole

Fig. 8. (a) Oil stain (artwork) (result)

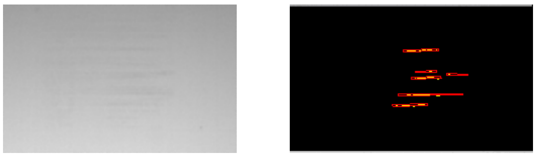


Fig. 8. (b) Stripe (artwork) (result)

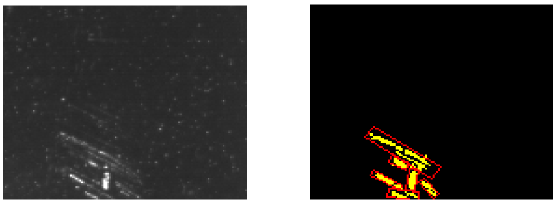


Fig. 8. (c) Scratch (artwork) (result)

Fig. 8. (d) Edge (artwork) (result)

Experimental results

Ten pieces of defected mobile phone panels were initially inspected by the eyes of factory quality engineer and theirs defect types were recorded. These samples were tested by the developed AOI system. Inspected results are listed in Table III. Comparing with the engineer's database, this system was proven to achieve 100% success rate certified by the factory engineer.

CONCLUSIONS

TABLE III
INSPECTION RESULTS (UNIT IN PIECE)

Defect	Hole	Oil stain	Stripe	Scratch	Imperfect edge
No. 1	0	0	0	2	0
No. 2		0	0	1	0
No. 3	1	0	0	0	0
No. 4	2	0	0	0	0
No. 5	1	0	0	0	0
No. 6	0	0	0	0	2
No. 7	0	0	0	0	1
No. 8	1	1	0	0	0
No. 9	0	0	1	0	0
No. 10	0	1	0	0	0

This study has successfully developed an automated optical inspection system for the film thickness measurement and defect inspection of the mobile phone panel. The film thickness of black coating is measured by the astigmatic principle of DVD pickup head. The low reflection signal is solved by the NFES technique so that the normalized FES signal is not affected by the surface reflectivity. The five types of defects are identified by the reference comparison method and classified by the proposed rule-based morphological operations. These two functions have been integrated into one measurement system with the replacement of the DVD objective lens by a commercial one that cannot only increase the depth of focus for film thickness measurement but also provide adequate FOV for defect inspection, being a two in one intelligent system. Experimental results show the satisfied accuracy of thickness measurement and 100% success rate of defect classification. The tact time of each image is about 0.1 seconds.

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手機面板自動光學檢測系統之研製

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摘 要

智慧型手機是當前最流行的消費產品，而潛在買家購買時的第一印象就是面板的質感，因此其重要性不言可喻。多數手機玻璃面板具有黑色的薄膜塗層，而面板表面的瑕疵和不均勻的塗層厚度會降低手機的外觀品質。因此本研究的目的是開發一個多功能的自動光學檢測系統，以應用於手機面板的生產線。

有別於一般商品化的系統只能單獨辨識表面二維的缺陷或三維的膜厚，本研究所開發的系統能夠同時檢測面板上的二維缺陷和玻璃塗層的 3D 膜厚的均勻性。2D 的表面瑕疵是由影像處理系統所檢驗，經由圖形識別技術，不僅可擷取表面的缺陷資訊，另可由形態學的技術分辨出缺陷的類型。

本研究使用一種低成本感測器，亦即利用 DVD 讀取頭製成的聚焦探頭，來測量薄膜厚度。實驗結果顯示，五種類型的表面缺陷，包括孔洞，油污，刮痕，條紋和邊緣，其可分辨的成功率達到 100 %。聚焦探頭使用均質化聚焦誤差信號（NFES）技術，可達到測量精度和標準差小於 0.1μm 的結果。