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Glass Defect Detection Techniques using Digital Image Processing –A Review

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*ABSTRACT***:Quality control is a crucial issue in a glass factory, and defects existing in floats glass can dramatically depress glass grade. This method inspects defects through detecting the change of image gray levels caused by the difference in optic character between glasses and defects. A series of image processing algorithm are set up around the analysis of glass images and the requirement of the online inspection system such as reliability and real time. Poor quality of glasses are due to the glass defects and many of times it may be obtain from embarrassment for manufacturers. It is a slow, time-consuming process to manually inspect very large size glasses. The manual inspection process is tediousand prone to human error. Automatic inspection systems using image processing and its applications can overcome many of these disadvantages and offer manufacturers an opportunity to significantly improve quality and reduce costs. So that efficient production of glasses at large levels needs glass defect detection using digital image processing.**

In this paper we review various glass defects and the possible automated solutions using image processing techniques for defect detection.

Keywords:**Defect detection, image processing, computer vision.**

I. INTRODUCTION

The quality control of the final product is a fundamental part of the glass production process, and this is demonstrated by the considerable scientific research that has been devoted to automatic inspection techniques These studies focus on using different approaches for defect detection depending on their specific application because no single technique can be considered optimal. As a result, many inspection techniques have been proposed with the aim of increasing the productivity and improving the final product quality. The quality control concept is the most vital aspect of the glass manufacturing industry. In the past human vision has played a primary role in quality inspection and verification processes. It is, however, now considered a limiting factor in the inspection of products coming out from modern industrial production lines, where high working speeds and very limited tolerances are required, unlike traditional defect detection mode which is slow and prone to errors. The solution to these problems has been the introduction of artificial vision-based inspection system. As a matter of fact, applications of these systems are nowadays widespread in many industrial sectors particularly the glass industry .For this industrial sector, an in-line automated inspection system that is able to discover, and classify the defects present in glass sheets has been developed and analysed. Though machine vision systems for automatically detecting visual defects, called mura, have been developed for thin flat transistor liquid crystal display (TFT-LCD) panels, they have not yet reached a level of reliability which can replace human inspectors. To establish an objective criterion for identifying real defects, some index functions for quantifying defect levels based on human perception have been recently researched. However, while these functions have been verified in the laboratory, further consideration is needed in order to apply them to real systems in the field. To begin with, we should correct the distortion occurring through the capturing of panels. Distortion can cause the defect level in the observed image to differ from that in the panel. There are several known methods to restore the observed image in general vision systems. However, TFT-LCD panel images have a unique background degradation composed of background non-uniformity and vignetting effect which cannot easily be restored through traditional methods. Therefore, in this paper we present a new method to correct background degradation of TFT-LCD panel images using principal component analysis (PCA). Experimental results show that our method properly restores the given observed images and the transformed shape of muras closely approaches the original undistorted shape.The majority of the scratches found on tempered glass result from poor glass quality. The surface quality of tempered glass will have a direct effect on the possibility of scratching the glass during cleaning. Low-quality tempered glass has fabricating debris fused to its surface, which at the time of cleaning has a very high likelihood of being dislodged and dragged across the glass surface, resulting in scratching.Due to the severity of scratches related to defective tempered glass it is vital that one be able to identify a

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batch of defective tempered glass as quickly as possible. There are a few major signs that identify low-quality tempered glass. The first is that scratches related to defective tempering are always widespread on the glass surface, usually covering the entire pane. The second is that scratching will only occur on the side of the tempered glass that was in contact with the rollers in the tempering furnace. The side facing up in the tempering furnace is usually defect free, and will not scratch when cleaned with the same window cleaning tools and techniques.Given the location of the furnace roller relative to the glass sample is so important, it is obvious that a method of determining which side was the roller side is vital. The key to this determination is the tempering stamp. Each tempered glass manufacturer has their own tempering stamp that they put on their glass samples (see photo of tempering stamp to the left). By identifying the location of the tempering stamp, the roller side of the glass can be determined. The important part in this determination is the type of tempering stamp. There are two major types of stamps used: sand blasted and porcelain. A sand blasted stamp is located on the roller side of the glass and will identify the potentially defective surface. A porcelain stamp is located on the side opposite the rollers and will identify the quality surface. This is a good time to point out that tempered glass is not always installed in the proper location in a building. Sometimes, with several windows being the same size, they are mistakenly installed in the wrong location. A check for the tempering stamp is the best way to determine if the glass is truly tempered. With regard to the glass industry, analyses and methodologies employed to detect the defects in the glass sheets mainly use image processing techniques because of their higher precision and speed A number of techniques that use machine vision defect detection system have been presented in the past, by various authors in their research on this topic. This paper reviews the types of glass defects and image processing algorithms for defect detection. An important safety element in motor vehicles which is often overlooked is the glass or "glazing." Not only do a vehicle's windows keep the elements out while allowing visibility, but the vehicle's glazing also serves as an essential part of the occupant restraint system.Optimal utilization of existing plant capacities through yield management and decreasing defective glass panels will help drive the cost of solar technology down. There are a number of challenges in controlling the quality of solar glass during the glass processing phase of manufacturing – cutting, grinding and tempering. In addition, solar panel manufacturers are concerned about incoming quality control of glass to optimize their production processes and reduce product warranty liability. Solar panels typically use two basic types of glass for front surfaces: super clear glass and patterned glass. Each of them has significantly different optical properties and may be processed on the same production line. The author will present the challenges and solutions to defect inspection and precision measurement for both types of solar glass. The presentation will include various techniques for precision measurement of solar glass and also techniques used to detect; differentiate and classify various defects including grinding defects. These methods are suitable for use by solar glass processing plants – cutting, grinding and tempering as well as for incoming quality control for solar panel manufacturers.

There are two basic types of glass used in vehicles today:

1. Laminated glass is what is in the windshield of your vehicle. It consists of two pieces of glass bonded to a transparent plastic interlayer. Although the glass parts of a laminated window still break the way ordinary plate glass does, the fragments stick to the interlayer rather than flying in on the vehicle's occupants. The fractured glass is contained in a small area radiating out from the initial break in a "star" pattern. The internal plastic layer also acts as a "safety net," absorbing energy from occupant contact while keeping the occupant inside the vehicle. This reduces possible brain injury as well as ejection. The laminate can also keep external missiles from entering the vehicle. It is legal to use laminated glass in any window in a vehicle.

2. Tempered glass, which cannot be used in the windshield but can be used in all other window openings of a vehicle, is plate glass that has been heat tempered to increase its strength. Because of the process used in manufacturing it, tempered glass is three to five times stronger than regular plate glass. The tempering process also affects the way the glass breaks. When one point in a window made of tempered glass is broken, the entire pane of glass fractures and disintegrates. All it takes is a pin-point hole in the outer surface, and the tempered glass completely fails. The fractured pieces are supposed to be small and without sharp edges; however, this is not always the case. The glass breaks from the inside out which causes the "clustering" effect of the glass. The internal fractures in the glass often do not come to the surface, the result being large groupings of glass fragments held together. These clusters can be several inches in diameter and have jagged edges.Even though laminated glass is generally safer than tempered glass, motor vehicle manufacturers prefer to use tempered glass in side, rear and roof windows because it is cheaper for them to manufacture. Defective glass or glazing can result in a number of injuries during a motor vehicle collision:

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1. It can allow an opening through which an occupant can be completely or partially ejected and thus severely injured or even killed.

2. It can cause blinding.

3. It can cause severe cuts, sometimes resulting in amputation.

Various defects—disruptions of the continuity or homogeneity of a material or deviation from the prescribed chemical composition, structure, or dimensions—occur in products as a result of the imperfect state of manufacturing processes or of operation under difficult conditions. Defects alter the physical properties of a material (such as density, electrical conductivity, and magnetic and elastic properties). The basis for existing methods of flaw detection is the investigation of the physical properties of materials upon exposure to X rays; infrared, ultraviolet, and gamma rays; radio waves; ultrasonic vibrations; and magnetic and electrostatic fields.Withover 30 years of experience in pursuing defective glazing claims, the lawyers of Wolff Ardis, P.C. should be your first call when you are considering a defective glass or glazing case.

II. TYPES OF DEFECT:

Once the glass sheet is manufactured, it is sent to the defect detection division of the glass production unit for testing and validation of defects. The various types of defects that can be present in the glass are:

A .Foreign material: This defect has the appearance of a lump. It is an unmelted, opaque material embedded in the glass.

B. Low-Contrast Defect regions: These defect areas are roughly

Defined as fairly large, several millimetres in diameter, and relatively dark and/or bright regions that stand out against the background.

C.Scratches and spots: These are the marks or irregular patches on the surface. These occur mainly during transportation within the factory. Flaws formed on freshly broken surfaces of glass reacted to various types of applied stress in a manner suggestive of dislocation type defects. Localized shear stresses caused existing defects to disappear and created new flaws which formed a cyclic pattern between parallel scratches made on newly created surfaces. These flaws formed behind the scratching tool and appeared to be associated with harmonically moving stress waves in the glass. Thermally induced stress energies were also found to increase the probability of flaw formation. Matching flaws were produced by nonuniform cohesion forces between internal crack surfaces. This effect was interpreted as the result of limited moisture penetration causing zones of reaction products and localized stress concentrations. The morphology of the defects indicated a dislocation within the glass which produced slip lines on the surface. The critical shear stress found to affect the flaws was determined by loading with spherical indenters.

D. Bubbles and inclusions: It is an air bubble like material trapped inside glass as a defect during its production.

E. Holes and dirt: These are the surface defects which cause major problems for manufacturers, particularly when the production process includes a surface treatment stage.

Different image processing algorithms are required for the detection of different types of defects which have been reviewed in the next section.

III. RELATEDWORK:

The apparatus for detecting surface defects of a glass substrate, having a dark field optical system, includes: a first photographing device for photographing first image; a second photographing for photographing second image; a dark field illumination system disposed below the glass substrate for serving as a dark field illumination; and a detection signal processor operating coordinates of a defect position on the first image and the second image, wherein the first photographing device and the second photographing device form photographing areas in the shape of lines which are not parallel to at least the transferring direction of the glass substrate, form photographing areas for a top surface of the glass substrate to be overlapped by each other and form photographing areas for a bottom surface of the glass substrate differently from each other.

Accordingly, the present invention has been made in an effort to solve the problems occurring in the related art, and an object of the present invention is to provide an apparatus and a method for detecting surface defects of a glass substrate, in which the high test power, the advantage of a dark field optical system may be secured as well as A/B surface distinguish function, so that a cycle time required for the distinguish of surfaces A/B for surface defects is reduced, and an inspector has to inspect surface defects of high NG possibilities only, thereby maximizing inspection engagement.

To accomplish the above object of the present invention, an apparatus for detecting surface defects of a glass substrate, having a dark field optical system, comprises: a first photographing device disposed above a glass substrate for

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photographing first images of surface defects on the glass substrate; a second photographing device disposed above a glass substrate for photographing second images of the surface defects on the glass substrate; a dark field illumination system disposed below the glass substrate for serving as a dark field illumination penetrating the glass substrate towards the first photographing device and the second photographing device; and a detection signal processor operating coordinates of a defect position on the first image and coordinates of a defect position on the second image; wherein the first photographing device and the second photographing device form photographing areas in the shape of lines which are not parallel to at least the transferring direction of the glass substrate, form photographing areas for a top surface of the glass substrate to be overlapped by each other and form photographing areas for a bottom surface of the glass substrate differently from each other. Further, a method for detecting surface defects of a glass substrate, comprises the steps of: generating a third image by synthesizing a obtained by a first photographing device and a second image obtained by a second photographing; and distinguishing on which surface the surface defects are generated according to a difference in a distance formed by the defects corresponding to the first image and the defects corresponding to the second image in the third image.

According to the apparatus for detecting surface defects of a glass substrate, the high test power as the advantage of the dark field optical system may be secured and simultaneously it is possible to distinguish on which surface the surface defects are generated, thereby exhibiting effects as follows.

It is possible to filter a large amount of surface defects which are generated on the surface B easily in short time, so that the inspection load of an inspector may be reduced and process efficiency may be increased.

The precision and engagement of inspection work for surface defects generated on the surface A may be improved since the amount of images to inspect is reduced, so that the use of improper glass substrates in mass production may be fully prevented.There has been considerable research in the field of defect detection in glass utilizing in-line automated inspection system. Some of the work done has been discussed one by one below.

In their paper, proposed a method for detecting foreign materials in the inspection of an LCD with its protective film in place, without being affected by scratches or dust on the surface of the protective film. The typical types and sizes of foreign material are listed in Table 1.

Table 1 Typical Foreign Material

Type	**Size**	**Source**
Glass Particle	200µm	Glass Polishing
Chemical Fibre& Glass Fibre	50 µm × 20mm	Cleaning Film Film & Glass Shearing
Resin Particle	100 µm cube	Film Shearing
Carbon Particle	250 µm	Glass Sheet Washing

Detecting only the foreign materials that are the cause of true product defects is problematic. Therefore, to avoid false detection of defects, it is necessary to know the position of the detected foreign material in three-dimensional space. In this method, which is based on the light-section method [12], the surface of the LCD is scanned under a fan-beam laser light to obtain a set of light-section time-series images.These images are composed into a horizontal cross-section image of the specified depth and internalforeign materials are detected from it.The processing power that is required for in-line inspection of a 60 millimetre by 30 millimetre or smaller LCD must permit an image acquisition time of one second or less and a foreign material detection processing time of two seconds or less. A new chemical etching technique was used to study minute flaw patterns in glass. The etched structure disclosed that the minute defects react to the chemical treatment in a different manner than ordinary fissures. Flaw patterns formed at the tips of slow-moving internal cracks were analogous to dislocation phenomena in crystals.

Oriented and repeating flaw groupings were observed in various types of glass. These patterns are produced above the ``strain point'' and were shown to be influenced by permanently induced stresses and internal homogeneity.

Fracturing by localized stresses created flaw patterns radiating from the point of origin with shapes similar in appearance to shock wave phenomena. The impact breaking strength of glass containers was directly influenced by the number of flaws. The flaw distribution decreased rapidly with decreasing diameter of glass fibres.

A standard TV camera is not capable of the required image acquisition speed; therefore it is necessary to establish a method for high-speed read-out of the camera image other than that of a surface image in the conventional wafer inspection By using commercially available 1300 by 1030 pixel high resolution CCD cameras, particulate contamination as small as 100 µm in diameter can be detected. Furthermore, by selectively reading a specified region of the camera image, the 600 frame/s image reading speed that is required for in-line inspection can be attained.

Foreign material detection tests on 100 samples of defective product showed that this method was able to detect all foreign material that has a minimum dimension of 50 µm, except for carbon particles of low reflectivity because the intensity of the

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scattered light was extremely weak. This problem can be reduced by improving the imaging optics to increase the detection sensitivity for the scattered light. Thus, the detection rate for the defective LCDs was 95%.

The MF estimator can successfully estimate model parameters from a dataset of contaminated Gaussian mixture. Such a noise model is defined as a regular white Gaussian noise model with probability 1-ε plus an outlier process with probability ε. The blemish defect in images can be considered as a group of outliers in the process of estimating image background model parameters.

The algorithm developed in this paper used a modified MF estimator to robustly estimate the background model and as a by-product to segment the blemish defects, the outliers. The illumination irregularity is made as a parabolic function; the centre area is made brighter than the perimeter of the image.

A zero mean Gaussian noise is added to the ground truth and the amount of noise, the standard deviation of the Gaussian noise, and the depth of circle of the ground truth are controlled for each simulation. In these simulations, the standard deviation of Gaussian noise is 8, i.e., SNR of 11.48, and the radius of circle used to simulate mura region is 64.

Another estimator mentioned in this paper [6] is the conventional Least-Square (LS) estimator which is used with polynomial function to enhance the illumination uniformity [7, 8]. For both the LS estimator and the MF estimator methods, threshold level are adopted as the 1.15 times σ. The post processing of the result image is performed to remove small and isolated noisy segmented pixels. The robustness of the two methods is measured by Underkill and Overkill ratios defined as the followings:

(Underkill Ratio) = # (detected)/# (circle)

(Overkill Ratio) = [1 - # (detected)/# (total)

Where # (.) means number of (.) pixels

Comparing LS and MF methods, it was found by the authors that the MF estimator is more robust than the LS estimator method in terms of Underkill or Overkill ratios. Both the Underkill and Overkill ratios of the MF estimator are always lower than the ones of LS estimator as the noise levels are decreased.

Reference [2] proposed an in-line PC-based visual inspection system to analyse the glass surface under inspection, which was able to discover and classify its defects and assess the product quality. A working prototype of this system was designed, built and tested to validate the proposed approach and to reproduce the real issues of an in-line quality control system. The developed prototype includes three subsystems: an array of several CMOS cameras, a controllable roller conveyor, and a PC-based image processing system that is also responsible for the control of the other subsystems.

The detection of the defects is performed by means of canny edge detection, with thresholds chosen according to some statistics of the images being processed. The defects detection algorithm has been applied to actual glass sheets and to batches of sample images. Defects (scratches and spots) could be identified as variations in structural parameters, deviations in size, and changes in texture features as shown in Fig.1 and Fig.2. In the proposed system the defects were perceived as irregularities in the random texture. Parallel Processing Toolbox of MATLAB was used. As expected, the processing time was reduced with the increase of the available processing power. Measured processing times were suitable for an in-line use of the system.

The system was tested in order to prove its robustness in a large variety of operating conditions. The system proved to be rather insensitive to variations and non-uniformities in the lighting subsystem. Additionally, the registration procedure was performed successfully, in spite of a bad illumination, even in dusty working environments.

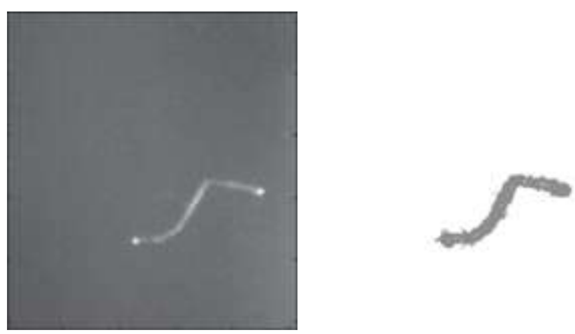

Fig.1. Example Of Identification And Classification Of a Scratcdefect. Dimensions are in pixels.

Jie Zhao, Xu Zhao and Yuncai Liu [1] proposed a method for detection of bubbles and inclusions. First, the defect region is located by the method of Canny edge detection, and thus the smallest connected region (rectangle) can be found. The defect region occupies very small part of the image, in comparison to the whole glass material. Segmenting the foreground region beforehand and performing the processing algorithms directly to the foreground can greatly increase the efficiency of the whole algorithm. Then, the binary information of the core

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region can be obtained based on an OSTU [4] and an adaptive algorithm. After noises are removed, a Binary Feature Histogram (BFH) is proposed to describe the characteristic of the glass defect. Finally, the AdaBoost method is adopted for classification. The classifiers are designed based on BFH. Experiments with 800 bubble images and 240 non-bubble images prove that the proposed method is effective and and efficient for recognition of glass defects, such as bubbles and inclusions.

Fig.2. Example of identification and classification of a spot like defect. Dimensions are in pixels.

In this experiment 467 bubble samples and 146 non-bubble samples are randomly selected to train the classifier for bubble detection. After the training, the final classifier consisted of 15 weak classifiers. The results were as follows:

- The recognition ratio of the non-bubbles is lower than that of the bubbles. The reason for these results could be that the sample number of the non-bubbles is not very large, and the non-bubble cases are relatively complicated than the bubble cases.
- The general accuracy of the recognition algorithm is 93.8%.
- The average processing period for one sample is around 0.048milliseconds, which can satisfy the requirement of the industrial production. The accuracy results can be seen in Table 2.

Table 2. Accuracy of the Test Data

Features	Total	Bubble	Non -Bubble
BFH	91.59%	92.22%	88.89%

IV. CONCLUSION AND FUTURE WORK

Automatic surface defect detection systems can bring manufacturers a number of significant benefits, particularly when used in-line. They can help reduce levels of scrap and improve quality, leading to both cost savings and increasing a company's competitiveness. Most commercially available defect detection systems use dedicated electronic circuitry. The increasing power and decreasing cost of processing electronics and the constantly improving performance of imaging sensors has widened the range of applications for which it is possible to configure cost-effective defect detection systems. This trend appears likely to continue.

Our future work will focus on:
1) Using more computational resources to improve the efficiency of defect detection techniques.
2) Reducing the complexity of thresholding and segmentation algorithms.
3) Working on multiple defects (e.g. scratches and inclusions together) 4) using single technique. Improving the machine learning method (e.g., attempt the algorithm of boosting for transfer learning).
5) Combining BFH with other features to obtain higher accuracy.

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