Glass Defect Detection Techniques using Digital Image Processing –A Review

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ABSTRACT
Glass defects are a major reason for poor quality and of embarrassment for manufacturers. It is a tedious process to manually inspect very large size glasses. The manual inspection process is slow, time-consuming and prone to human error. Automatic inspection systems using image processing can overcome many of these disadvantages and offer manufacturers an opportunity to significantly improve quality and reduce costs.

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.

1. INTRODUCTION
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 [9], 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 analyzed [3]. 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 [13]. 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 [11].

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 [5]. 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.

2. 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:

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

Low-Contrast Defect regions: These defect areas are roughly defined as fairly large, several millimeters in diameter, and relatively dark and/or bright regions that stand out against the background.

Scratches and spots: These are the marks or irregular patches on the surface. These occur mainly during transportation within the factory.

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

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.

3. RELATED WORK
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.

Makoto, Akira and Toshio [10], 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 Fiber & Glass Fiber	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 internal foreign materials are detected from it. The processing power that is required for in-line inspection of a 60 millimeter by 30 millimeter 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 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 [14]. 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 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%.

To detect the low-contrast regions on glass, a highly robust estimator, known as the Model-Fitting (MF) estimator [6] was developed by X. Zhuang et al. and successfully used in many computer vision applications. 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 center 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 analyze 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 scratch defect. 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 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 efficient for recognition of glass defects, such as bubbles and inclusions.

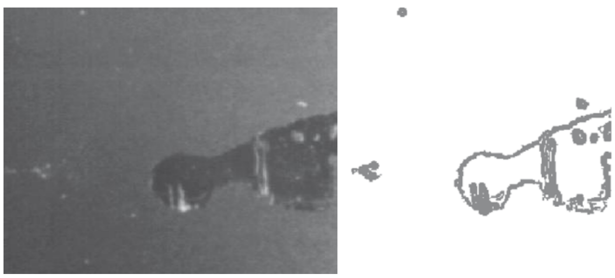

Fig.2. Example of identification and classification of a spot like defect. Dimensions are in pixels.

In this experiment [1], 533 bubble samples and 167 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 91.6%.
- 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%

4. 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) using single technique. 4) 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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