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VISION TECHNIQUES FOR THE INSPECTION OF TABLEWARE GLASS PRODUCTS

Key words

Machine vision, quality inspection, tableware glass.

Abstract

The paper presents an analysis of the capability of developing a system for on-line inspection of tableware glass products. In the first part of the article, basic imaging techniques for dimension measurements and flaw detection are presented. As part of the experimental studies, inspection techniques are proposed for the detection of typical defects of tableware glass products. Example experimental results for selected products are discussed. The article proposes a solution based on a special lens used to inspect holes that enable the detection of cracks in the sides of glass products using a single camera. In the final part of the article, based on literature review and experimental studies, the authors summarize machine vision techniques used to assess the quality of glass products.

Introduction

The rapid development of optoelectronics contributes to the growing use of optical measurement methods and the rapid development of machine vision [1].

Based on the report "Machine Vision Market" developed by MarketsandMarkets research firm, it is predicted that the market for machine vision will increase from 8.08 billion dollars in 2015 to 12.50 billion in 2020 [2]. One of the most important factors that have an effect is a growing need for quality inspection in industrial production. Quality control is a very broad concept covering many aspects of the production process, and it is closely related to the manufacturing industry and the type of production [3]. The development of new technologies allows the use of non-contact methods for quality inspection while maintaining reasonable financial outlay, which can often be recovered after a few months as a result of the reduction of waste. Quality inspection plays an important role in the success of a commercial product. Accordingly, the on-line systems replace statistical quality inspection techniques to ensure 100% inspection of all products made.

In general, quality inspection systems can be divided into two categories: measurement systems and defect detection systems. Inspection by measurement of selected parameters is a quantitative method that allows checking whether the measured data meet their manufacturing tolerances. In turn, detection of defects is a qualitative method that determines whether the controlled objects have undesirable defects [4].

”Glass Industry Roadmap,” which was developed under the auspices of the US Department of Energy, presented critical challenges to productivity, such as advances in the modelling of processes, quality inspection, and control systems. The intended target for the glass industry by 2020, among other things, is to achieve the quality level of ”Six Sigma” for the glass products [5]. One possible solution to achieve this is the use of vision systems.

1. Imaging techniques

Glass products require on-line inspection in production lines, which should guarantee the highest efficiency of the detection of defects (nearly 100%) and the lowest percentage of so-called false positives. The process of automatic optical inspection can be divided into the following steps [6]:

- Image acquisition in fixed lighting conditions,
- Recording images in the memory of the computer system, and
- Processing and image analysis using appropriate algorithms.

A high transmissivity of glass products for the visible light spectrum can be used for simultaneous detection of surface defects and the internal structure of the materials. In the inspection of glass products, there usually are two methods used for image acquisition: a reflective system or a transmissive system [7] (Fig. 1).

a) b)

Fig. 1. Applied imaging systems: a) reflective system for image acquisition, b) transmissive system

- Imaging in a reflective system: In this type of solution, a camera captures the radiation reflected from the object of inspection (Fig. 1a).
- Imaging in a transmissive system: In this method, the test object is illuminated in the direction of the camera, which captures radiation reaching the sensor due to the transmission through the structure of the object (Fig. 1b).

2. Advanced imaging techniques

In addition to the main imaging techniques used during the testing of transparent products, there are also specialised techniques for detecting specific defects.

During the inspection of glass products, one of the operations is the detection of cracks on the sides. The defects of this type are particularly important because of the possibility of damage to the product in transit or during use. One of the methods that can detect such flaws is the use of lighting system in the dark-field configuration [8], wherein the illuminator is directed perpendicularly to the direction of the optical axis of the camera (Fig. 2). With this arrangement, in a region of the occurrence of defects in the form of material discontinuity, there appears multi-directional light diffusion, which is recorded by the camera.

In areas where there are no defects on the analysed images, any changes in intensity are not visible and only the dark background is recorded.

Where the cracks occur, fractured edges can be observed with high brightness compared to the nearest surrounding, which can be detected using the appropriate detection algorithms.

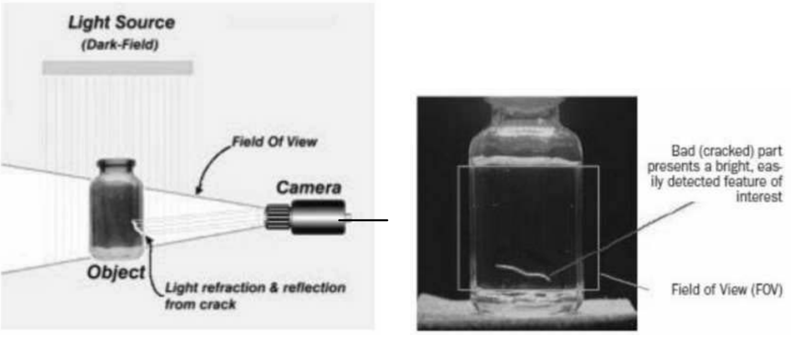

Fig. 2. The system of observation with the *dark-field* illuminator [9]

One of the phases of the production of glass, which occurs usually after its formation, is the annealing. For this reason, it is necessary to effectively evaluate the stress in order to eliminate defective products, because incorrect stress patterns may be associated with the risk of cracking or other damage. Thanks to the development of advanced optoelectronic technologies and computer-based image analysis, it is now possible to develop automated methods for measuring residual stresses on-line in production lines [10].

3. The test stand

In order to carry out the verification of methods for the inspection of glass products, it was necessary to develop an experimental test stand. During the implementation of individual imaging systems, a system for the modelling of visual inspection process developed in Institute for Sustainable Technologies – NRI in Radom was used (Fig. 3). The apparatus consists of the following major components:

- An integrated vision controller from Keyence,
- Linear motion module to transport the tested objects,
- The operator's panel for motion control module,
- A camera to observe from the top,
- A camera to observe from the side,
- A monitor to visualise the results of inspections and for system configuration, and
- A LED illumination system (ring illuminator, panel illuminator).

a) b)

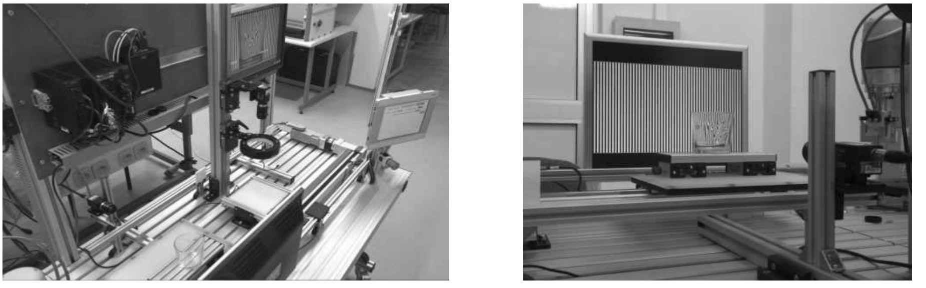

Fig. 3. Test for modelling the visual inspection process: a) general view, b) example of the use of structured illumination

Within the research work, the stand was additionally equipped with a PC, and a LCD monitor, which was placed behind the inspected object (Fig. 3b). This arrangement for imaging allowed the use of the structured light techniques to detect specific defects in glass products.

4. Geometrical measurements

The identification of dimensional defects includes measurements of height and diameter, thickness, ovality, and eccentricity. During the development of inspection systems for a typical glass factory, the high variability of dimensions of controlled items should be considered; therefore, the vision system should be flexible. In order to avoid a complicated calibration and parameterisation of the inspection system, it is a good solution to use telecentric lenses. The advantage of this type of lens, unlike the standard lens, is to ensure a roughly constant image magnification over the operating range of observation. Telecentric lenses are also characterised by small measurement errors resulting from the effect of perspective, so a change in the position of an object in the field of view of the lens does not significantly affect the image distortion [11, 12].

The disadvantage of this solution is the considerable cost of the lens, which increases exponentially with the increase in the maximum field of view (FOV) (Fig. 4). The necessity to meet the condition of mutual parallelism of the light rays to the optical axis of the lens makes the lens face diameter greater than the diameter of the required field of view. Accordingly, the size and weight of a telecentric lens is significantly larger than an analogous standard lens.

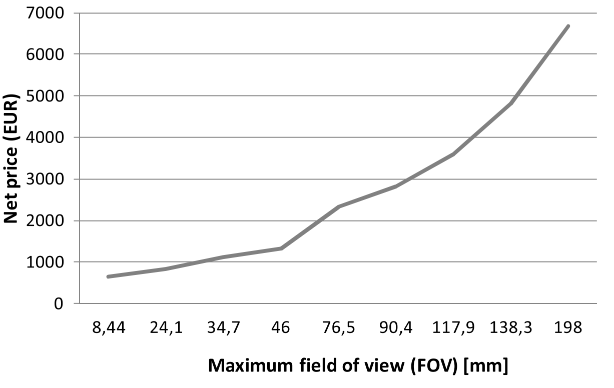

Fig. 4. Price chart for telecentric lenses depending on the field of view (developed based on prices available on the Graftek Imaging [13])

Along with the greater field of view of telecentric lens there is also an increase in its total length, and its working distance of observation is also greater, which can translate into construction problems related to ensuring the required working space. One solution is the use of mirrors positioned at 45 degrees to the axis of the optical system [14] or integrated lenses containing both the lens and mirror in a compact package [15].

5. Internal and surface defects

Glass products with typical defects that occur on the sides that are formed during the manufacturing process were tested. In each of the presented cases, a transmissive imaging system was used. In the descriptions of defects, the terminology was adopted from the glass industry. The visible markings on the products are defect annotations made by quality inspection personnel.

The glass products can contain defects such as cracks visible on the lateral surface. The effectiveness of detection of this type of defect is dependent on its location. In the situation when it is at a considerable distance from the optical axis of the camera (Fig. 5a) it exhibits a distinct edge. If the defect is near the optical axis, it is very difficult to identify. A defect in the form of an incomplete upper edge can be detected by analysis of the trend line of the upper edge of the cup (Fig. 5b). Glass products may also contain defects in the form of inclusions or trapped air bubbles (Fig. 5c). This type of defect causes a high contrast in the inspection area. After applying the operation of binarisation and morphological filters, the defect can be effectively identified by means of a BLOB detection algorithm or by analysing the average level of intensity in a given area.

a) b) c)

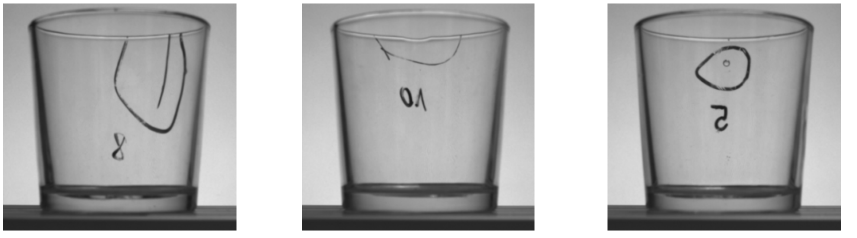

Fig. 5. Sample images of defects of glass products: a) crack on the side surface, b) a distortion in the upper edge, c) inclusion in form of an air bubble

Other types of optical defects are deformations, which involve the presence of local distortions of surface geometry. This phenomenon occurs during glass tempering, when deformation occurs when the glass surface is visible in reflection, with minor prints on a glass surface [16]. The defects of this kind are not critical from the point of view of security, but due to the quality standards should be rejected at the production stage. In the case of defects in the form of optical deformations, it is not possible to detect them using a standard transmissive imaging system (Fig. 6a). A method that allows the identification of such defects is to use a LCD display that emits the appropriate patterns of stripes. Where the defects occur in the recorded images a distortion of the projected stripes can be seen (Fig. 6b), which can be identified using an algorithm defining the relative distance between successive lines of the pattern, since this distance should be approximately equal in areas free of defects (Fig. 6c).

a) b) c)

Fig. 6. Sample images of optical deformation occurring on glass products: a) an image using the standard transmissive system, b) image using projection of stripes, c) the edge detection in a region free of defects

The method described above allows the detection of occurring optical deformations without measuring the degree of the disturbance of surface geometry (qualitative method). In order to determine the size of geometric deformation occurring on the surface of the selected product, further research was carried out that focused on the scanning of the surface of glass products using the measured head that used a 2D laser triangulation technique. On the surface of the object, the line formed by the laser light projected by the lens system is displayed. The light reflected from the object surface is then projected through a lens system on a light sensitive array positioned at an angle with respect to the projection direction of the laser light on the test surface. The change of the distance between the points of illuminated surface relative to the measuring head changes the position of the images of those points on the light-sensitive matrix [17]. In order to scan the surface of the side of the test products, it is additionally required to ensure their rotation relative to the laser head. Information obtained from the measurement system in conjunction with location information from the positioning table allows the recreation of the geometry of the surface of the object based on a set of registered profiles.

When scanning glassware, measurement interferences associated with double refraction of the laser beam on the border between the two transparent media occur (air - glass - air) (Fig. 7).

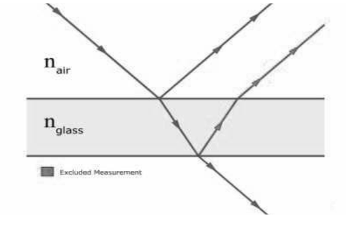

Fig. 7. Presentation of the double refraction of the light beam at the border of media [18]

To reduce measurement noise, the glass surface was sprayed a thin layer of white powder before scanning the side surface. The powder has a thickness of several micrometres, and it is commonly used in the detection of cracks on material surfaces [19]. During scanning, the powder is intended to form a thin, uniform, and fine-grained matte layer on the surface of the examined object. Figure 8 presents the general view of the stand used to scan the side surface of the products.

Fig. 8. The test stand to scan the side surface of products

Examples of the results of the scan as a development of the side surface are shown in Figure 9. In the central area of the graph, the maximum disturbance occurring on the geometry of the external surface of the products is displayed. The recorded deformation level occurring on the surface is approx. 0.1–0.2 mm.

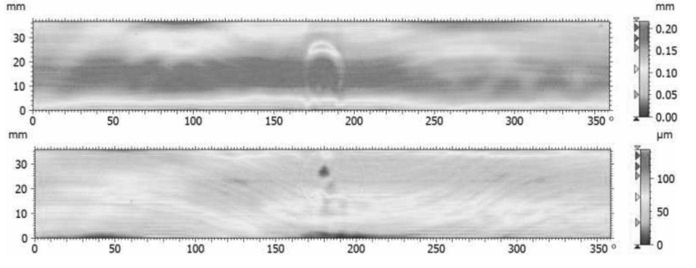

Fig. 9. Examples of results of the scan side surface of the product with defects in the form of geometric deformation

The presented method of scanning the side surface of glass products using a 2D laser head is not suitable for the rapid quality control of the production line. The purpose of this study was to confirm the presence of disturbances and to measure the geometry of the surface of glass products, which can be seen as an optical deformation disqualifying the product due to the visual qualities.

Another type of defect, which must be detected before the packaging of the product, is a crack perpendicular to the axis of the glass. This type of defect is created after moulding when it is picked up by a special gripper and then put on the transporter. The standard method used to detect such cracks is to use previously described techniques of dark-field lighting. However, that solution requires the use of a multi-camera system that allows full control of the sides. Moreover, this type of defect has a very small thickness when observed from the side of the product, which requires the use of cameras with higher resolution. In order to increase system reliability and reduce its complexity, the authors have developed a method that uses a special lens dedicated to the inspection of internal surfaces of holes (Fig. 10a).

a) b)

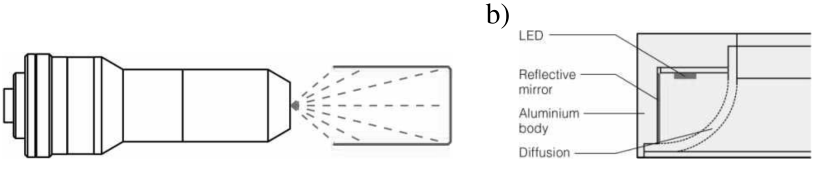

Fig. 10. The selected main elements of the proposed imaging system: a) a specialised lens designed for the inspection of holes [20], b) multi-angle ring illuminator (internal structure) [21]

Due to the very high angle (> 82°) and a small working distance, the lens allows the inspection of the inner surface of the objects with a diameter of 10 mm to 120 mm and height from 10 mm to 190 mm. To illuminate the field of observation, a multi-angle ring illuminator is used (Fig. 10b). With the right configuration of the surface of a diffuser and multi-directional light emission, it is possible to evenly illuminate the side surface of the tested products.

The use of the proposed imaging system (Fig. 11a) provides a very high contrast of areas where a crack occurs (Fig. 11b).

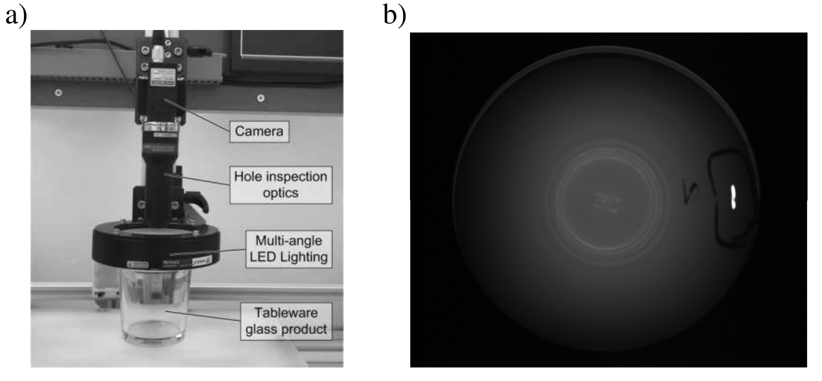

Fig. 11. A method of the inspection of the sides of glass products for the presence of transverse cracks: a) the proposed imaging system, b) sample image with a visible defect in the form of cracks

Observed from the top, the edge of the defect has a much greater thickness, which is proportional to the thickness of the sidewall of the product. Another advantage of the developed imaging system is the ability to use a single camera to inspect the entire side surface of the glass products. Where cracks occur in the image, they can be observed as areas of high brightness compared to the nearest surroundings.

Conclusion

Comprehensive on-line inspection of products made of transparent materials is a demanding task for contactless systems. The article presents methods for assessing the quality of glass products based on techniques of machine vision. Based on the literature study, traditional inspection methods used in such applications were classified and discussed. The results of the laboratory work have shown that, in order to ensure full control of products made of glass, a multi-camera vision system is required. Most of the identified inspection techniques apply back lighting techniques. However, in the case of specific defects in glass products, there are also more sophisticated techniques used. In order to detect defects in the form of optical deformations, the only effective solution is the use of the active light methods with structured light.

At the stage of the implementation of visual inspection, an important issue is its high level of sophistication and complexity. In order to reduce the total number of required cameras to allow a full inspection of the product, the authors proposed a solution based on a special lens used to inspect holes. The high observation angle of applied optics allows the inspection and detection of cracks in the sides of glass products in the full range of 360 degrees. The performed experiments confirmed that the presented solution is characterised by high reliability and efficiency of detection.

The planned further work on improving the methods of inspection of glass products will be focused, among others, on the use of imaging systems using other ranges of electromagnetic radiation outside the visible band. Another direction of development will be to develop a complete inspection system enabling the control of various glass products of non-typical shapes.

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Techniki wizyjne stosowane do inspekcji produktów szklanych

Słowa kluczowe

Wizja maszynowa, kontrola jakości, szkło użytkowe.

Streszczenie

W artykule przedstawiono analizę możliwości opracowania systemu kontroli jakości on-line produktów szklanych. W pierwszej części artykułu zaprezentowano podstawowe techniki obrazowania umożliwiające pomiary wymiarów geometrycznych oraz wykrywanie wad. W ramach badań eksperymentalnych zaproponowano techniki kontroli jakości dla typowych wad produktów szklanych. Omówiono przykładowe wyniki doświadczalne uzyskane dla wytypowanych wyrobów. W artykule zaproponowano rozwiązanie oparte na specjalnym obiektywie wykorzystywanym do kontroli otworów, które umożliwia kontrolę i detekcję pęknięć ścian bocznych produktów szklanych przy zastosowaniu pojedynczej kamery. W końcowej części artykułu, na podstawie przeglądu literatury i przeprowadzonych badań, autorzy dokonali podsumowania technik wizji maszynowej stosowanych do oceny jakości wyrobów ze szkła.