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INSPECTION OF TABLEWARE GLASS PRODUCTS WITH USE OF STRUCTURAL BACKLIGHT

Key words: machine vision, quality inspection, glassware, structural backlight.

Abstract: The paper presents a method for defect detection in tableware glass products using a structural backlight system. In the first part of the article, the designing of the imaging system is described. Furthermore a real-time system for generating pattern images is presented. Finally, laboratory tests carried out using the developed system and algorithms for image processing and analysis are described.

Inspekcja wyrobów szklanych z wykorzystaniem tylnego oświetlenia strukturalnego

Słowa kluczowe: wizja maszynowa, kontrola jakości, produkty szklane, oświetlenie strukturalne.

Streszczenie: W pracy przedstawiono metodę detekcji wad w wyrobach szklanych przy wykorzystaniu tylnego oświetlenia strukturalnego. W pierwszej części artykułu zaprezentowana została struktura opracowanego systemu obrazowania. Następnie opisano system czasu rzeczywistego do generowania obrazów z wzorcami. Zaprezentowano opracowane algorytmy przetwarzania i analizy obrazów oraz przedstawiono rezultaty testów wykonanych za pomocą proponowanego systemu.

Introduction

The glass manufacturing process consists of several stages in which a number of monitoring and inspection techniques can be used [1]. The final product quality control is made before the packaging process at the end of production line. A high transmissivity of glass products in the range of visible light spectrum can be used for simultaneous detection of surface and internal structure defects. Most of the flaws such as cracks, inclusions, or bubbles cause a high contrast on images acquired with use of a standard backlight system (Fig. 1) which ensures reliable detection.

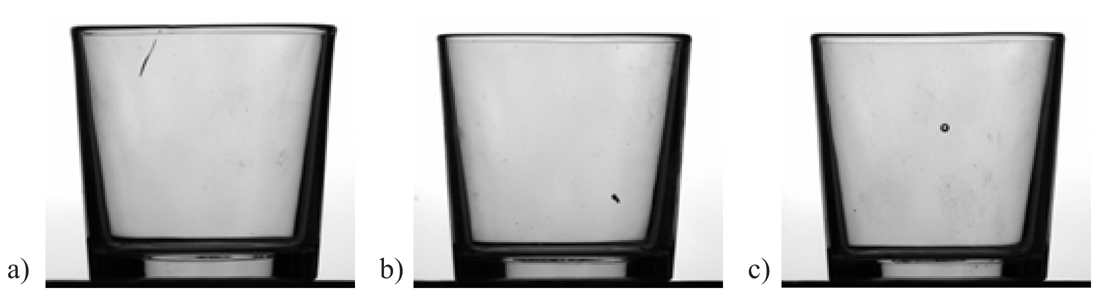

Fig. 1. Images of example defects acquired with use of standard back light system: a) crack, b) inclusion, c) bubble

However, defects occurring by the presence of local distortions (Fig. 2a) of surface geometry cannot be easily detected on a production line with use of a standard backlight setup (Fig. 2b).

a) b)

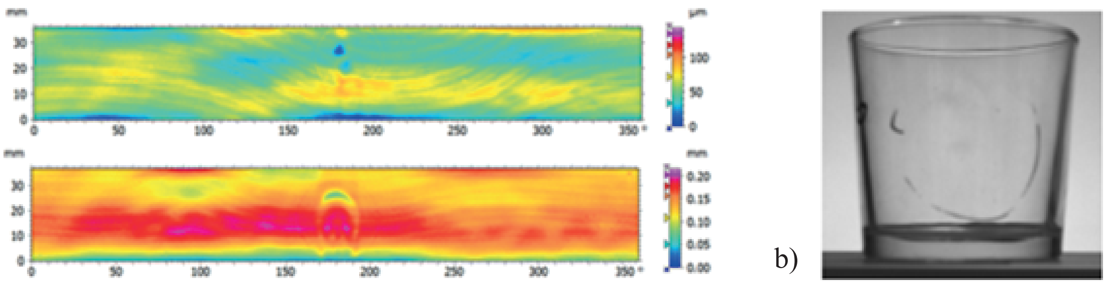

Fig. 2. Geometric deformation defects of glass products [2]: a) Examples of results of the scan side surface, b) backlight image

This defect arises as a result of accidental disturbances in the technological process. It is the result of air closure between the moulds on the wall of the glass product during the pressing process. Even a good process operator cannot completely prevent this defect. It can happen accidentally and be unnoticed in mass production. Only automatic inspection of each article can eliminate this defect from the batch sent to the customer. Fortunately, it is possible to recognize this type of defect with use of backlight deflectometry [3]. This method involves the analysis images of a known pattern that is emitted by source and passed through the transparent object which allows emphasizing possible geometry distortions (Fig. 3).

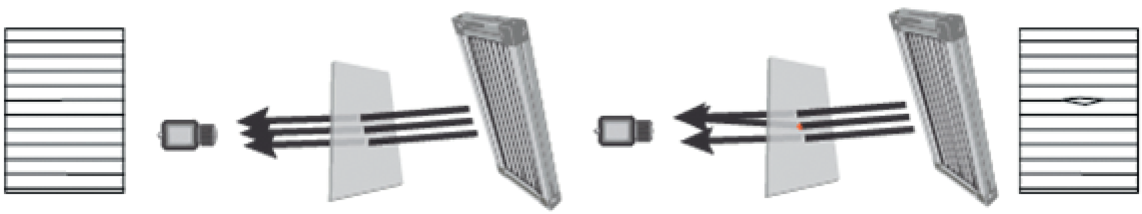

Fig. 3. Transparent objects and phase measuring deflectometry [3]

One of the possible solutions is to use commercially available LED illuminators with one type of pattern printed on the surface [4]. However, due to the random nature of geometric defects and a large variety of shapes of glass products, this solution does not guarantee reliable detection. In order to increase the effectiveness of the inspection system, it is necessary to apply a solution enabling the generation of various types of patterns depending on the shape of the product and the type of defects expected.

1. Inspection systems structure

Preliminary laboratory tests carried out in stationary conditions allowed determining general assumptions for the inspection system. In accordance with the adopted concept, the proposed system consist of two imaging setups placed perpendicular to each other [Fig 4a.]. In order to improve the repeatability of the system, telecentric lenses [5] have been used. Furthermore, to reduce the size of the imaging system in the final system, classical telecentric lenses have been replaced with a compact solution design by Opto Engineering [6] [Fig. 4b].

a) b)

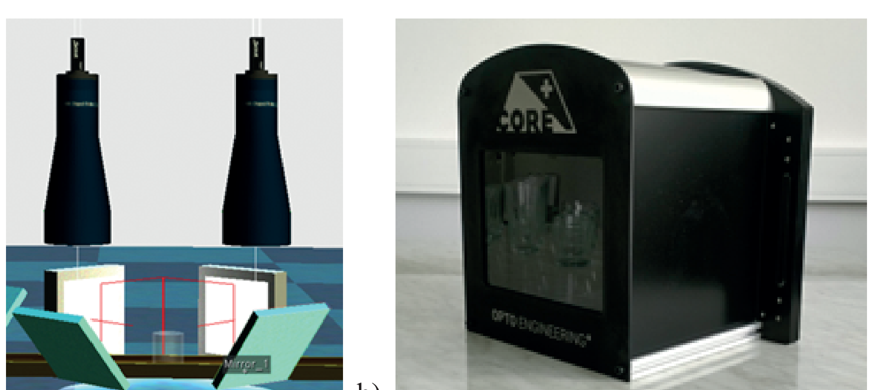

Fig. 4. Inspection module for geometric flaws detection: a) concept of imaging system with classical telecentric lenses and mirrors, b) compact telecentric lens.

Due to construction size limitations and requirements for obtaining the appropriate imaging resolution, the field of view of lens must be chosen. It is worth noting that one of the disadvantages of telecentric lenses is that they must be larger than the maximum observed scene [7]. Depending on the number of images to be used for analysis and the acquisition rate of the entire system, the size of the lens field of view should be chosen accordingly. In the proposed system, a TCCP23144 lens from Opto Engineering was used which has a maximum field of view 145x121 mm.

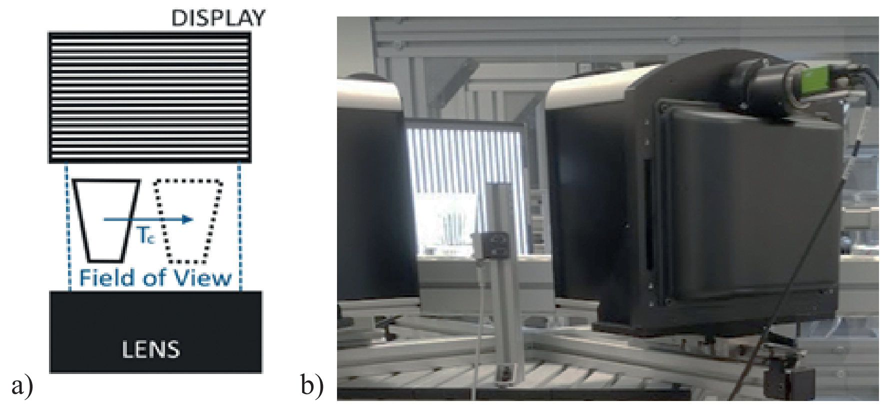

Fig. 5. Imaging setup for multi-image acquisition [own elaboration]: a) concept, b) laboratory stand

A very important issue during the development of the system was to select a reliable system for generating sequences of different patterns. In the target manufacturing line, products that are inspected are transported on the production line at a speed above 0.5 m/s. Therefore, the basic criterion for the pattern display system was shortening the response and pattern visualization time and guaranteeing its repeatability. In general, the complete image acquisition cycle time T_c should be less than time needed to move the inspected product outside of the lens field of view (Fig. 5a). Another critical issue was the selection of appropriate display, which was due to the fact that the inspected articles move at high speeds on production line. It has become important to select a high-brightness display that would allow the use of the shortest exposure time and thus reduce the blur effect [8] on the analysed images. Standard displays have a brightness of approx. 350 cd/m2, which is not enough to use short exposure times. In the designed system, a Litemax DLH1568 [9] display was used that has basic parameters that are as follows: brightness is 2000 cd/m2, the response time is 8ms, resolution is 1024x768, and the display area is (mm) 304.13(H) x 228.1(V) mm. To control the acquisition process of a series of images, a dedicated system has been developed to work in real time (RT). The RT controller monitors signals from the LED through-beam photoelectric sensor responsible for detecting the presence of the object and generates structured images to the display and synchronizes the camera frames acquisition (Fig. 5b). The generated images are black and white with vertical, horizontal, or diagonal stripes (optional) with a specific width and angle (for diagonal stripes). Images are vector generated, so no extra memory is required to store them. The generated images are saved on a special, fast RAM memory for graphics. Time charts of individual signals of the acquisition system are shown on Figure 6. Image 1 is displayed until the signal (We1) from the trigger system is activated (Fig. 6). This signal informs the system that the object has appeared in the field of view of the camera. When the appropriate signal appears, the microcomputer sends a signal to the camera (Wy2). Then it waits for the falling edge of the confirmation signal that the camera has finished the acquisition process of Image 1 (We3). Image 2 is displayed after the confirmation signal. After that, the confirmation signal of Image 1 is displayed again, and the microcomputer waits for the next signal from photoelectric sensor. In the developed system, when using two types of strip patterns, the cycle time is below 50 ms.

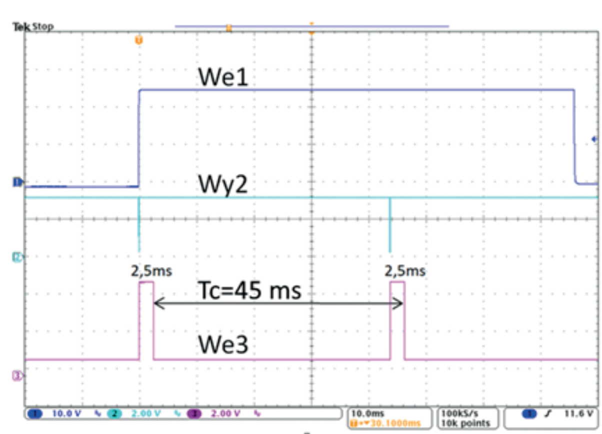

Fig. 6. Time charts of individual signals-image acquisition system

2. Image processing and analysis

The developed inspection algorithm is implemented on a Matrox 4Sight EV6 [10] vision controller. In the presented case, the general inspection procedure can be grouped into the following stages:

1. Region of Interest adjustment,
2. Detection of stripe edges on sub-regions,
3. Global distortion analysis, and
4. Final decision.

In the first stage of the inspection procedure, the exact position of tableware glass is determined. For this purpose, the outer edges of the glass are detected and its centre is calculated (Fig. 7a). Then the inspection window is positioned relative to calculated value (Fig. 7b).

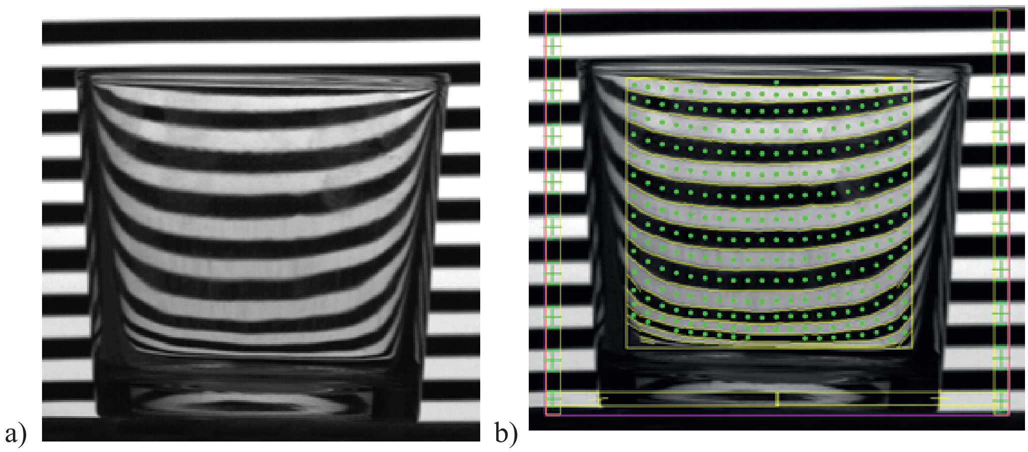

Fig. 7. Example image of inspected article: a) camera raw image, b) positioning algorithm for inspection window (yellow rectangle)

In the second step of the algorithm, sub-regions are created in the inspection window in which the positions of the black and white stripe edges are detected. The sub-regions are in the form of a rectangle with the long side perpendicular to the direction of the stripes in the background (Fig. 8a). Based on the determined positions of the stripe edges, areas are then identified in which the angles of a single stripe edges are different from each other beyond the accepted tolerance (Fig. 8b). In addition, in areas where the edge angles are accepted, the width of stripe is also checked to determine if it complies with accepted range (Fig 8c).

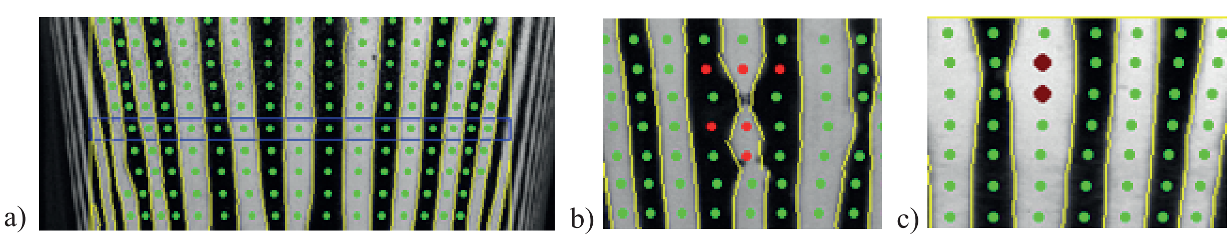

Fig. 8. Example image: a) detection of edges in the sub-region (blue rectangle), b) stripe angle defect (light red circle), c) stripe width out of range (dark red circle)

In the next stage, global analysis of the controlled area is performed on the basis of local inspection results from sub-regions. The final decision is made on the basis of the number of areas with small defects and their distribution or the occurrence of a critical defect in the local sub-region.

3. Experimental results

The conducted tests where made with use of a laboratory stand (Fig. 9) developed at Łukasiewicz-ITeE within the project "Creation of the Intelligent Specialisation Centre in the Field of Innovative Industrial Technologies and Technical and Environmental Safety" financed from the Regional Operational Programme of the Mazowieckie Voivodeship 2014–2020. The main objective was to check the effectiveness of the developed detection algorithms in conditions close to industrial reality. The products were transported in a closed loop at the speed corresponding to the maximum production capacity of the target glassworks. For this reason, camera exposure times were reduced below 3ms to avoid blur on the images being analysed. However, due to the low contrast in the images during the image acquisition, the binning technique was used, which solved this problem but simultaneously reduced the image resolution to 1280x1024 pixels.

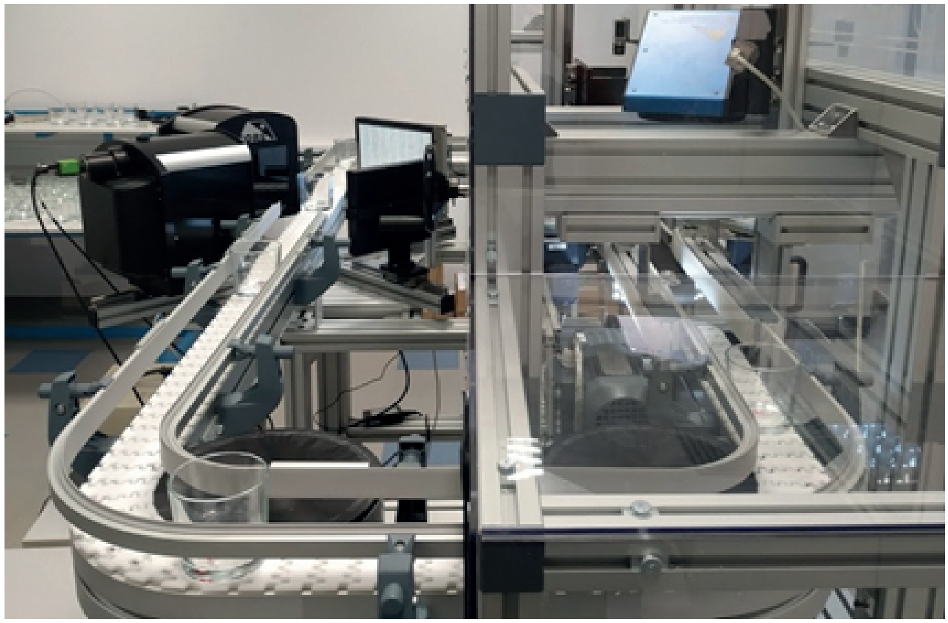

Fig. 9. Closed-loop laboratory test stand

During the tests, a system using two types of stripes patterns was evaluated. Based on the results obtained, it should be stated that this is the minimum number of patterns that provides an acceptable level of defect detection. Due to the different deformation of the surface, some defects are more pronounced when using vertical rather than horizontal (Fig. 10) stripes and some defects are more pronounced when using horizontal rather than vertical stripes. It is also worth noting that typical defects are visible in the same way when rotated 180 degrees. Therefore, the preliminary assumption about the use of two optical paths is correct.

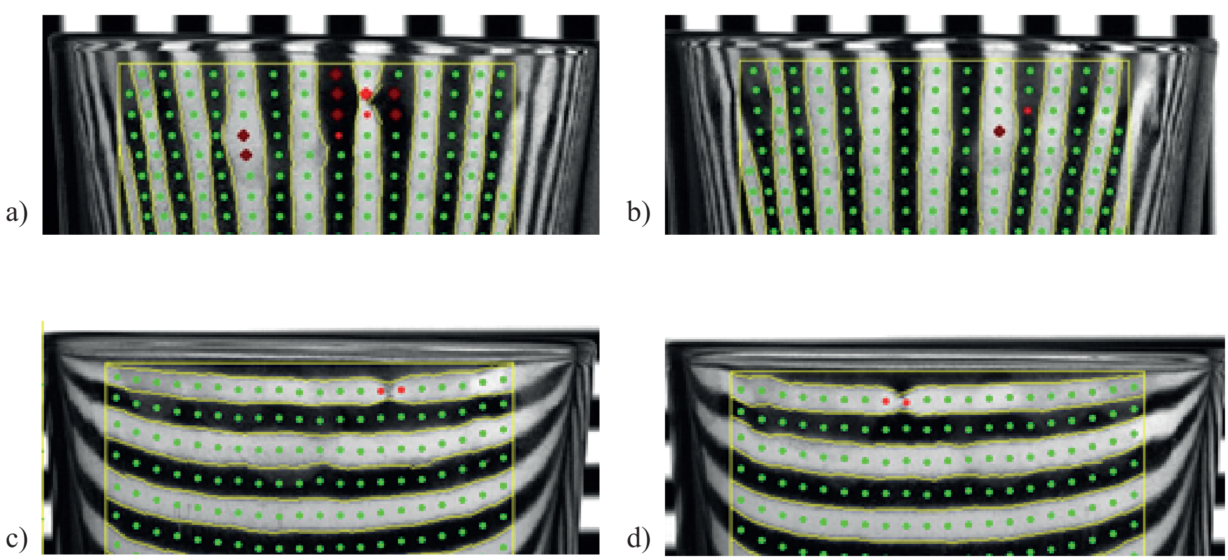

Fig. 10. Example images of tableware glass product at different rotary position and patterns: a) vertical stripe – 0°, b) vertical stripe – 180°, c) horizontal stripes – 0°, d) horizontal stripes – 180°

In the 100 articles tested, there were 40 defective products that were 100% correctly classified. However, a significant percentage of false identifications (approx. 5%) were also observed. A large number of these identifications can be caused by a subjective assessment of the glassworks quality control department stuff. Therefore, the level of system sensitivity must be determined in the future in order to achieve the highest level of productivity while eliminating significant flaws.

Conclusions

The growing demand for better and more reliable inspection systems for many manufacturing industries leads to the development of more sophisticated solutions. The costs of inspection system installations are not only considered in terms of return on investment but also in terms of the company's reputation and achieving quality above the standard level present on the market. Although the defect for which the presented detection system is dedicated is not critical in terms of product safety, the large number of articles it can inspect justifies its use to reduce the number of entire batches of glass products being returned to the glassworks. This is also associated with high costs of customer complaints.

The presented method is characterized by the high efficiency of optical distortion detection. However, it can cause a significant level of false-positive identification. For this reason, proper parameterization of detection algorithms by system operators is very important. In addition, it allows one to detect other types of defects such as cracks or inclusions, which further increases the reliability of the entire inspection system. A limitation of the proposed method may be the increase in dimensions of the cold-end inspector, which, in many cases, can prevent installation at the end of the production line.

Future work will be focused on building a prototype system to be tested on the production line. Tests carried out under real conditions will allow the verification of the proposed method. Another direction of research will be implementation of additional types of stripe patterns in the designed imaging system.

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