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Non-Contact Techniques for the Quality Analysis of PET Bottles

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***Abstract* – This work was motivated from finding a complementary way of tuning and controlling the machine parameters of Injection Stretch Blow Molding process. In the current approach, a specialized technician detects the bottle defects by visual inspection and corrects the machine parameters using its own experience or indications obtained by previous statistical analyses. As all human based operations, inherent limitations are that the results are influenced by the operator skills; in addition, the experience can be hardly converted into a database, which could be used for the process optimization. The solution investigated in this work is to replace visual inspection with an image processing system. A prototype for off-line analyses of PET bottles was designed in order to have a resolution allowing to identify the most common bottle defects. The acquired images were analyzed with algorithms implemented in LabVIEW. Results showed that this system can off-center gate, haze and pearlescence with a repeatability and reproducibility sufficient for the identification of bottles with manufacturing defects.**

I. INTRODUCTION

In recent years, the need of lowering the costs and environmental impact of plastic bottles production has brought to a continuous reduction of the quantity of material used in the process. This operation is not straightforward, as an excessive reduction of the bottle thickness increases the risk of production wastes and decreases the overall quality of a bottle. Nevertheless, as Injection Stretch Blow Molding (ISBM) is a very complicated process, fulfilling this demand is still not an easy task for industries. Currently, ISBM machines are controlled by a combination of statistical methods and operator intuition and experience. In particular, the machine parameters are manually tuned for every bottle type and for different environmental condition. As the physical phenomena involved in ISBM are strongly non-linear and the material needed to build a single bottle is continuously decreasing, small variations of uncontrolled variables which influence the process require the retuning of the machine. As a consequence, the development of an automatic procedure to carry out this calibration or the feedback control of the machine parameters during production phase would be very welcome.

The simplest way to accomplish this is to replicate with a machine, the procedure already performed by operators. Mainly, the decision is based on the kind of defects found on the final product [1-3]. Consequently, the first step to achieve the long term goal is to automatically detect the main defects affecting the bottle; the main bottles defects are:

a) Internal folding in the neck area
b) Excessive material in the base of the bottle
c) Off-Center Gate
d) Pearlescence in Bottle Walls
e) Bottle Features not Shaped Properly
f) Distinctly Visible Split-line
g) Non Uniform Wall Thickness over Circumference
h) Non Uniform Wall Uneven Axial Wall Distribution
i) Lack of bottle axial symmetry

Examples of some of these defects are shown in Figure 1: the images show examples of internal folding in the nech area (a), excess of material on the base (b), off-centered gate (c), pearlescence (d) and four examples of petaloid not correctly shaped (e1 – e4)

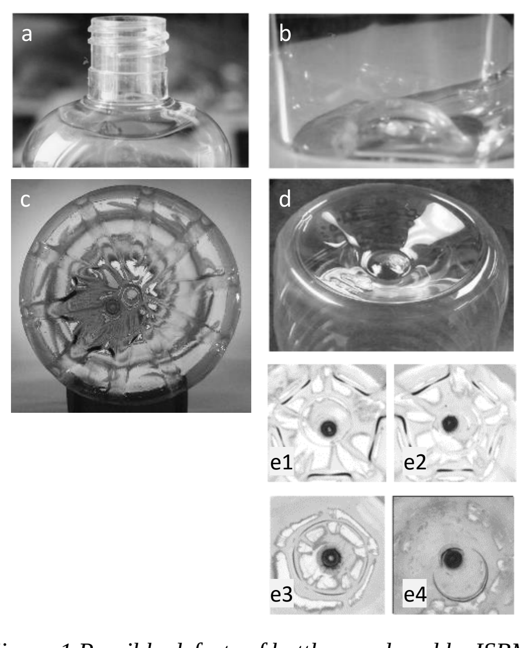

Figure 1 Possible defects of bottles produced by ISBM.

The type and the entity of the defect suggest the corrective actions that must be undertaken to tune the ISBM process. This procedure is usually based on a trial and error strategy, as clearly explained in [1,3].

This work aims to design a system capable of identifying the defects of the bottle and to quantify their entity, in order to identify the corrective actions that must be taken to optimize the bottle production. Our idea is to acquire and analyze the images of the bottles in order to overcome the limitation deriving from the subjective evaluations of the operators. In the literature, there are little studies focused on the identification of defects of PET bottles produced with the ISBM process. Huang and Liu [4] studied the growth of PET preforms using a transparent mold. Images of the preform during the ISBM phases were captured, but the work was focused on the identification of the preform growth type (and not on the bottle defects). Feng et al. proposed the adoption of machine vision for the analysis of the bottle finish [5] and of the presence of liquid in recycled bottles [6]; the research was focused on glass bottles and consequently the type of defects under investigation were different from those analyzed in our work. Scavino et al. [7] proposed a system that uses the machine vision to identify and extract the plastic bottles on a conveyor system. Authors developed a recognition algorithm designed to overcome difficulties such as poor lighting and, deformed bottles, so the usefulness for the scope of our article is limited.

At the current state of the art, there are no literature studies focused on machine vision systems for the identification of the most common defects of PET bottles manufactured with the ISBM technique. In this work we investigate the possibility of using simple machine vision techniques for the identification of the bottles defects. The proposed method and the experimental setup are descried in section 2; experimental results are presented in section 3 and discussed in section 4. The paper conclusions are drawn in section 5.

II. METHOD

A. Experimental setup

The experimental setup uses two cameras in order to acquire images of the lateral and of the lower surface of the bottle. The optical characteristics of the cameras and their distances from the bottle were identified with basic geometrical considerations, imposing an optical resolution of 0.1 mm and the possibility of acquiring images of bottles with capacity of 2 l. The focal length of the lenses and the distances between the bottle and the cameras were computed in order to obtain a good trade-off between the depth of field of the cameras and the layout compactness.

The distances between the rear and the lateral cameras and the bottles (OD_x and OD_y) are equal to 220 and 270 mm, respectively.

The scheme of the experimental setup is shown in Figure 2, while the characteristics of the measurement setup are summarized in Table 1.

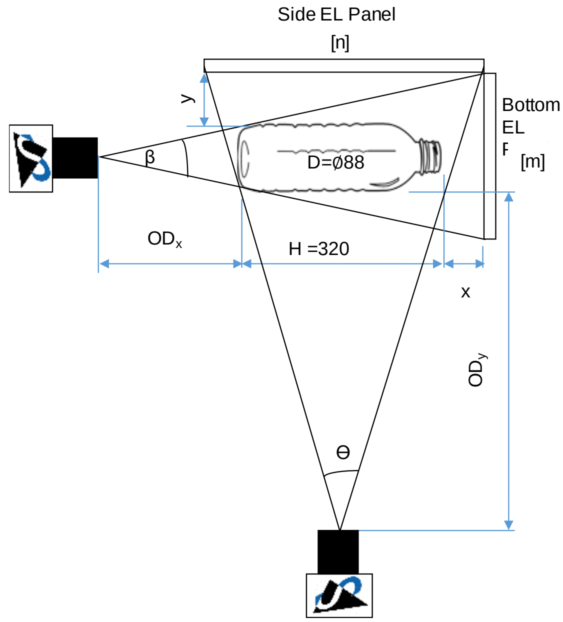

Figure 2 Scheme of the experimental setup

Table 1 Characteristics of the measurement system

Component	Specification
Cameras	DMK 72BUC02 (grayscale, resolution 2592 x 1944 pixels, framerate 6 fps
Lenses	T 2314 FICS-3, focal length 8 mm
	T 0412 FICS-3, focal length 4 mm
Lighting System	Electroluminescent Panel 310 x 310 mm
	Electroluminescent Panel, 150 x 580 mm
Frame	Bosch Rexroth Profile (40 x 40 mm)

The images of the experimental setup are shown in Figure 3. The setup is based on the bright-field lighting technique, i.e. the bottle is located between the light source and the camera and the light is generated by electroluminescent panels. The bottle is closed in a box with opaque walls and the camera is kept in its position using by an aluminum frame. The latter was built with Bosch profiles in order to be able to modify the distance between the camera and the bottle for the analysis of bottles with different nominal capacities.

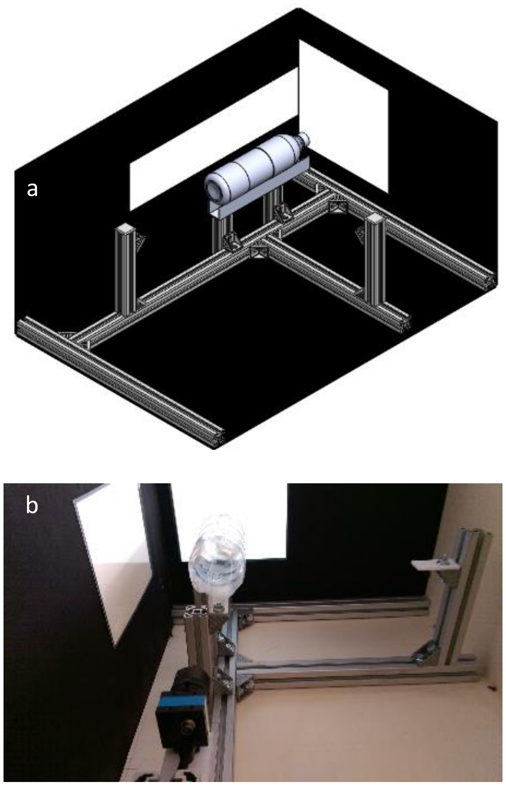

Figure 3 Pictorial views of the experimental setup

B. Data Processing

The software for the image analysis was developed using LabVIEW. Preliminary analyses were performed in order to understand the optimal acquisition parameters using the DOE approach [8]. The camera aperture was the minimum allowed by the lens, in order to obtain a decent depth-of-field; the gain was set to the lowest bound and the acquisition time was 0.6 s, in order to obtain the best possible image quality. An image of the software interface is shown in Figure 4.

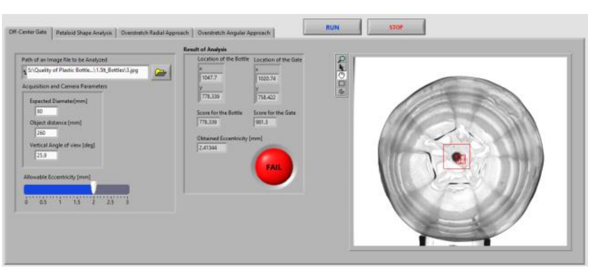

Figure 4 A screenshot of the user interface.

The first group of analysis focuses on the bottle base, that is usually the most critical one. The base can be divided into three regions:

1. the central region, where the distance between the injection point (gate) and the center of the bottle is the metric for quantifying the off-center defect. The latter is caused by a wrong material distribution on the bottle side wall;
2. an intermediate region, analyzed to identify the shape of the petaloid. The incorrect shape of the petaloid indicates problems deriving from the final stages of bottle molding t and usually implies the presence of other defects.
3. The external zone can be affected by over-stretching, which results in haze or pearlescence of the final product.

The three zones are shown in Figure 5.

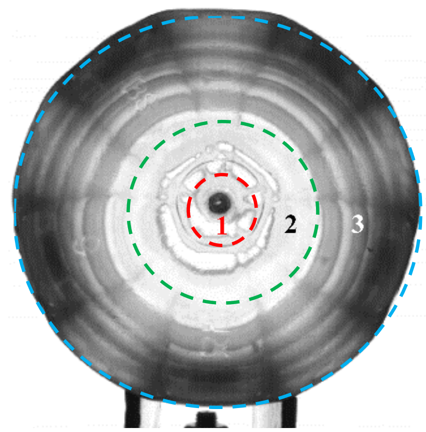

Figure 5 Image of the three zones of the bottle base used

The first defect analyzed is the off-centered gate; the adopted metric is the distance between the geometrical center of the bottle and the location of the injection point. Different techniques were preliminary analyzed; the most robust was the pattern matching of the external bottle profile paired with the pattern matching of the injection point. The distance in mm was then compared to the manufacturing tolerances.

The second defect that our system is deputed to measure is the wrong petaloid shape. The defect is detected by analyzing the intermediate region (zone 2 in Figure 5) in two ways:

1. a pattern matching technique to identify the petaloid features, as shown in Figure 6; and
2. the analysis of the greyscale level in polar coordinates.

Figure 6 clearly how the pattern matching can be used to identify the number of dark features and their positions; differences between a correctly shaped bottle (a) and a partially formed one (b) are evident.

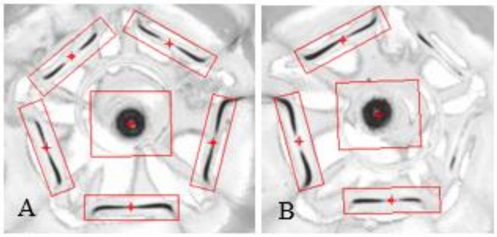

Figure 6 Pattern Matching for Petaloid Analysis

The second technique is based on the computation of the normalized gray scale value along the angular direction. In the annulus of Figure 7 (a), the greyscale level has a periodic behavior with a high 10 x revolution harmonic component.

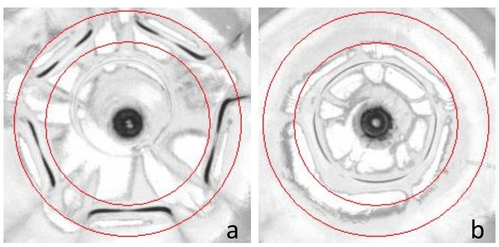

Figure 7 Polar petaloid analysis for a correctly shaped bottle (a) and bottle with the petaloid not shaped (b)

In the bottles with the defected petaloid (as Figure 7 (b) or Figure 6 b) the 10 x Revolution component is much smaller, as shown in Figure 8. The typical values of the 10^{th} harmonic ranged between 0.3 and 0.4 for correctly shaped bottles and was lower than 0.1 when the petaloid was not shaped correctly.

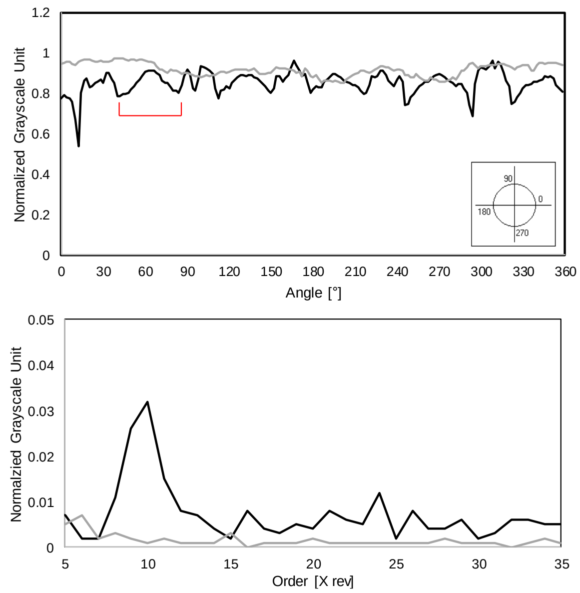

Figure 8 Signal obtained from the analysis of the annulus in Figure 7 (upper plot) and corresponding spectrum. Dark line, correctly shaped bottle; grey line, bottle with petaloid defect.

The last defect analyzed was the presence of overstretching, which results in pearlescence and haze of the bottle base. The main idea for the identification of the overstretching is to analyze the gray scale value distribution along the radial direction. The effect of overstretching results in a lower gray scale value in the external annulus of the bottle (Zone 3 of Figure 5). A comparison between two images of overstretched and non-overstretched bottles is shown in Figure 9.

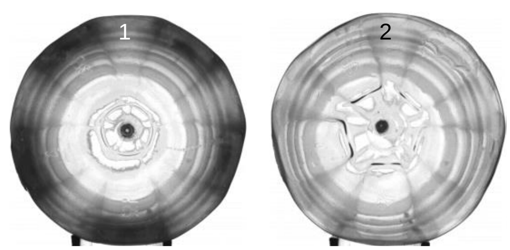

Figure 9 Overstretched (1) and non-overstretched (2) bottles

The grayscale level along the radial direction of the two bottles shown in the upper image is shown in Figure 10; the plot shows that for radii larger than 28 mm the grayscale level of overstretched bottles is lower than that of correctly shaped bottles.

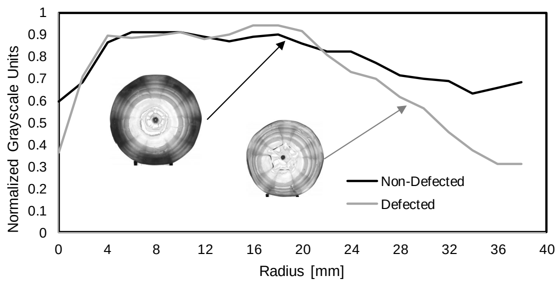

Figure 10 Overstretching analysis

The analyses of the lateral surface were limited to the identification of the external bottle profile, that was compared to that of a correctly shaped bottle. In this case, the figure of merit was the distance between the measured external profile and the profile of a correct bottle; an example is shown in Figure 11.

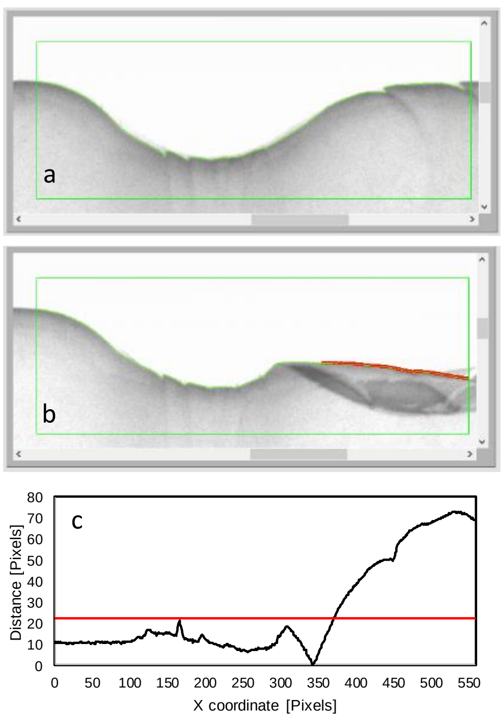

Figure 11 Analysis of the lateral bottle surface: Reference profile (a); profile of a bottle with a defect (b) and distance between the bottles with and without defects (c).

III. RESULTS

The repeatability and reproducibility of measurements was analysed by using the proposed methods on different types of bottles. Repeatability tests were performed by measuring the same quantity on the same bottle, while the experiments' reproducibility was evaluated comparing the results of families of bottles with and without defects.

The typical test included the acquisition of 10 images of the same bottle with random orientations (i.e. placed and removed 10 times in the measurement setup). For each type of defect, we have analysed 4 different bottles, thus analysing 40 images per defect. The effectiveness of the proposed algorithms was evaluated analysing the average and the standard deviation of experiments.

As an example, Figure 12 shows the comparison of experiments' repeatability and reproducibility of the overstretching analyses. The standard deviation is definitely small in comparison with the difference between the bottles with and without defects for radii larger than 25 mm.

Similar analyses were performed also for the identification of the petaloid shape and of the off-center gate. Results evidenced the validity of the proposed methods, given that the standard deviation of experiments repeatability and reproducibility were always much smaller than the differences between the bottles with and without defects.

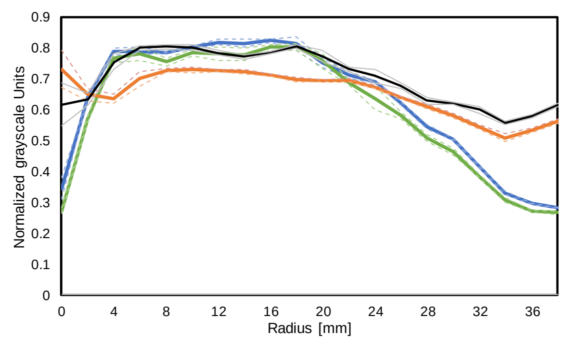

Figure 12 Repeatability and reproducibility of overstretching analysis (overstretched bottles: orange and black curves; standard bottles: blue and green curves).

IV. DISCUSSION AND CONCLUSIONS

The demand of high quality PET bottles leads to task of intensive optimization and control of ISBM process. The presence of nonlinear phenomena in the ISBM prevents from the adoption of an analytical approach and the detection of bottles defects with a fit-to-purpose measurement system allows providing a feedback for the entire manufacturing process.

The proposed method for the identification of defects is based on two cameras; the first one observes the lateral surface of the bottle and the second captures image of the bottle base. In this first phase, the bottle has to be manually positioned in the measurement device. Different image processing techniques were used for the identification of the major bottle defects. The validity of the proposed approaches was proven by the repeatability tests: results showed that the standard deviation of repeatability (which is representative of the method uncertainty) is generally much smaller than the differences existing between compliant and not-compliant bottles.

The good repeatability has been obtained by capturing the images in a dark box, so that the effect of the external light is minor. A similar result could be obtained using cameras with larger sensors (such as digital single lens reflex cameras) coupled with stronger backlight sources. In these condition, the use of short exposure time should allow taking images also inline, thus allowing the quality control on single bottles.

V. REFERENCES

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