Building a Low-Cost Device for an Automatic Inspection of Blow-Molded Plastic Tubes

Luis Unzueta, Javier Barandiaran, and Álvaro Segura

***Abstract*—**In this paper we present a low-cost system based on computer vision algorithms, which automatically inspects blow-molded plastic tubes used as outer covers of car dampers. The small size of the typical defects, the dark color and the specular reflection of this kind of black plastic parts makes the automation of this process a challenging task. Customers are becoming more exigent and they can even reject full batches of thousands of pieces only because of some non-valid samples (e.g., a limit of 10 defective tubes per million), therefore a correct quality checking is very important for companies. There are several standard industrial solutions designed for the automatic inspection of several kinds of pieces but not for these specific tubes. The proposed computer vision method obtains the tube surface aspect from the deformed laser beam projections observed by an uncalibrated camera, and identifies defects by comparing its shape with respect to the one expected. Experimental results show the suitability of the system to detect holes, burrs and deformations of these tubes, improving the quality checking process at a low cost.

***Keywords*—**Computer Vision, Defect Detection, Plastic Tube, Quality Inspection.

I. Introduction

THERE are several solutions for the automatic inspection of industrial pieces [1], but there is not still a satisfactory one for the inspection of blow-molded plastic tubes due to their shape, color and the shininess of their surface. Therefore, the inspection of this kind of pieces is usually done by operators that practically cannot do anything else. They have to take the tubes just released from the blowing machine, visually verify their quality and reject those with non-admissible failures.

These pieces are built in the following way: firstly, the cast polymer emerges from a pipe and falls forming an extruded hollow profile called parison (left image of Fig. 1). Once this has an adequate length, the two part mold covers it and compressed air is injected inside. Consequently, the parison expands to occupy the interior of the mold and then it cools down to get its form. Finally, a set of rotating blades cut the piece with the desired length and the mold opens up to let the tube fall down with its definitive shape (right image of Fig. 1).

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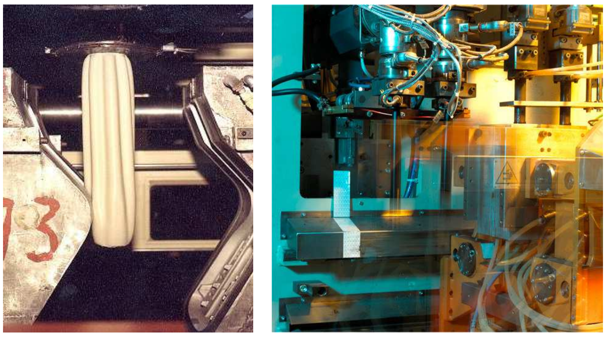

Fig. 1 On the left, a plastic parison falling between the mold's two parts, and on the right, the REINER blowing machine for tubes used as outer covers of car dampers [17].

As it can be seen in Fig. 2, the typical failures of these tubes can be small and difficult to be quickly detected. Apart from being a cumbersome task for humans, it is prone to errors: the operator may not do the work paying the same attention for hours and it is usual to let some failures pass through [2]. The problem is that clients are becoming more exigent and, in occasions, they reject full batches of thousands of tubes due to a reduced number of non-valid pieces (e.g., a limit of 10 defective per million), which can lead to economic and logistic breakthroughs to manufacturing companies.

The typical approach to determine if a piece is correct, in Industry, is to obtain its 3D reconstruction and then compare it with respect to a canonical shape, which usually corresponds to the CAD model of its design. There are several techniques to reconstruct the real 3D shape of objects for further quality inspection: e.g., stereo vision [3]-[5], Time-of-Flight (ToF) [6], digital fringe projection [7], space-time stereo [8] or structured light approaches (see [9] for a review), which include, laser based solutions [10], binary encoding [11]-[13], encoding by means of multiple grey-level values [14][15] and De Bruijn sequences based methods [16].

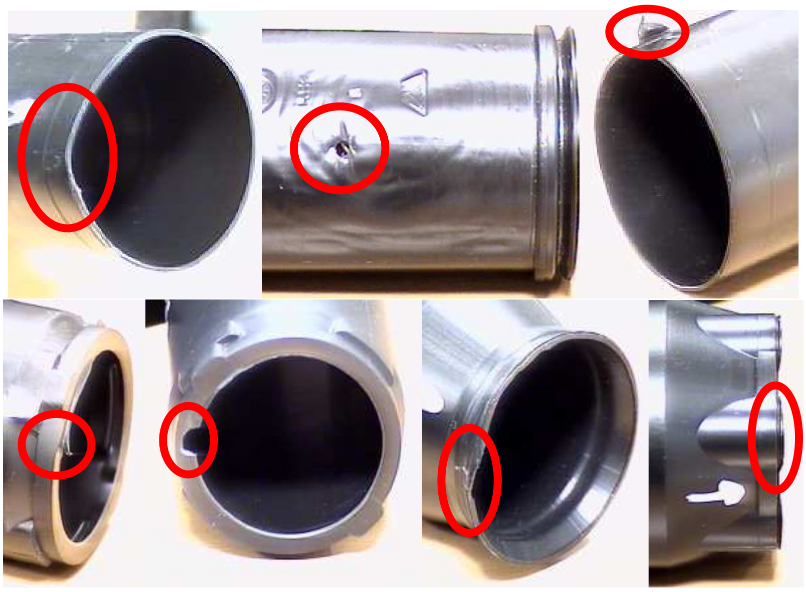

Fig. 2 From left to right and top to bottom: a deformed tube, a hole, a burr and diverse defective cuts.

However, these techniques are not the most suitable to reconstruct these tubes for detecting failures on them, fast enough to increase the productivity of the quality assurance process. The dark color of the material and specular reflection of their surface prevent to visualize clearly their projections in 2D images and therefore invalidate the techniques based on directional illumination or light patterns. On the other hand, their tubular shape makes it difficult to obtain the 3D reconstruction quickly as many high resolution calibrated views are needed to obtain a good enough quality to detect small failures.

In this work we show how to build a low-cost system based on computer vision algorithms to reconstruct the shape of the surface of this kind of tubes, with precision using an uncalibrated camera and a laser beam. This system allows detecting deformations, holes and burrs on them, at a high speed using existing computing devices. Experimental results with tubes from REINER [17], show the suitability of the proposed system and methods for the automation of these tasks, improving in this way the productivity of blow-molded tube quality control process.

II. Related Work

There exist specific solutions for the reconstruction of industrial pieces and the detection of failures on them, depending on the type of piece, material, and/or defect. For instance, Biegelbauer and M. Vincze [18] focused their work on bore surface inspection using a robotic 3D vision-guided system that can deal with small and medium lot sizes. Beyerer [19] explained key ideas for the automated visual inspection for core shops and foundries, and remarked the importance of sophisticated illumination techniques and elaborated optical front ends for such task. Bonnot [20] aimed his efforts at detecting scratch and lack of machining defects on metallic industrial parts with streaked surface, and used for it a trained classification, created with well known typical objects of each class. Budd [21] patented a solution that allows the inspection of large cast machined surfaces without movement of the component, sensor or illumination system during acquisition of an image. Smith and Smith [22] described an approach for two- and three-dimensional surface data capture from moving surfaces, based upon an evolution of the existing photometric stereo technique. Later on, Farooq *et al.* [23] adapted and extended these concepts for the high speed inspection of ceramic tiles. Pernkopf and O'Leary [24] presented an adaptive threshold selection algorithm for image segmentation, usable for the inspection of bearing rolls, where the surface reflectance properties are modeled and verified with optical experiments.

In order to attain a more generality on X-ray inspection systems for non-destructive testing, Herold *et al.* [25] showed how a flexible automatic defect recognition system can be achieved using software building blocks to cope with all the different requirements and demands.

In the case of tubes similar to those studied in this paper, Picon *et al.* patented a solution, described in [26], which achieves the inspection of each extreme side of metal tubes with a rotating scanner, usable for detecting failures such as defective cuts or deformations in those tube regions. Nevertheless, we demonstrate in this paper that it is not really necessary to perform the complex task of calibrating the views in order to detect deformations, holes and burrs on the surface of blow-molded tubes.

III. Tube Shape Reconstruction

Blow-molded tubes can be reconstructed using a standard 3D scanner. However, apart from being a time-consuming task which would certainly lower the productivity of the checking process, it is not a satisfactory method to find holes and burrs on it. Fig. 3 shows an example of the 3D scanning of one of these tubes. It can be seen that even if the mesh has a high enough density in order to model correctly holes, it is not capable of doing it (the hole's position is marked in red). The distance between obtained surface vertices is smaller than the hole but, due to the small hole size and the dark color of the tube, the system is not able to distinguish between the hole and the surface at that place, and hence it “detects” some surface mesh vertices that do not correspond to the tube’s real shape.

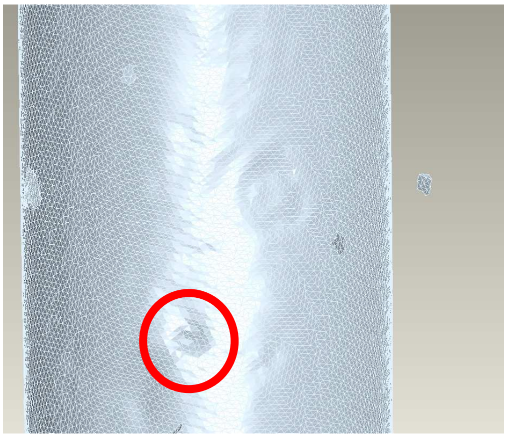

Fig. 3 An example of how a standard 3D scanner cannot detect a hole even if the point cloud density is high enough.

On the other hand, it can be seen in Fig. 4 how a burr is modeled as a hole in the mesh. This happens because the system is not capable of modeling the abrupt laser deformation at that place with precision. It would be a good way of detecting burrs, but it is not in this case because, as it can be observed in the image, holes appear in the mesh even where there are no actual holes or burrs in the real object. Moreover, there are also some other small and isolated mesh regions “in the air” which should not be there. All these scanning errors occur because of the difficulty that the scanner has with the specular and dark surface of this kind of tubes.

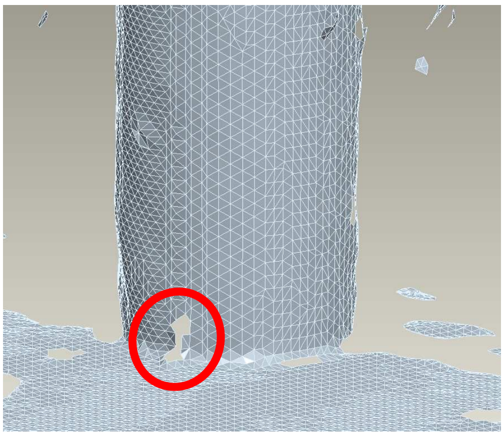

Fig. 4 An example of how a 3D scanner models a burr as a hole.

The quality of this 3D reconstruction could have been improved if we would have applied on the tubes a thin matt and light liquid (or spray) to turn them into diffuse reflectors, but this is not suitable for our purpose of automating the failure detection process at a low cost.

Instead of using this approach, we propose two system layouts to reconstruct the tube shapes. Both are composed of a linear laser beam perpendicular to the piece’s axis and a camera that observes the resulting laser projection profile from an oblique point of view (top image of Fig. 5). The differences between both set-ups are the relative distances of the components and that in one of them the tube rotates around its axis while in the other the tube moves along it. Additionally, in the case of the translating set-up, as it is necessary to verify the whole surface, further cameras and laser beams, or various passes would be required.

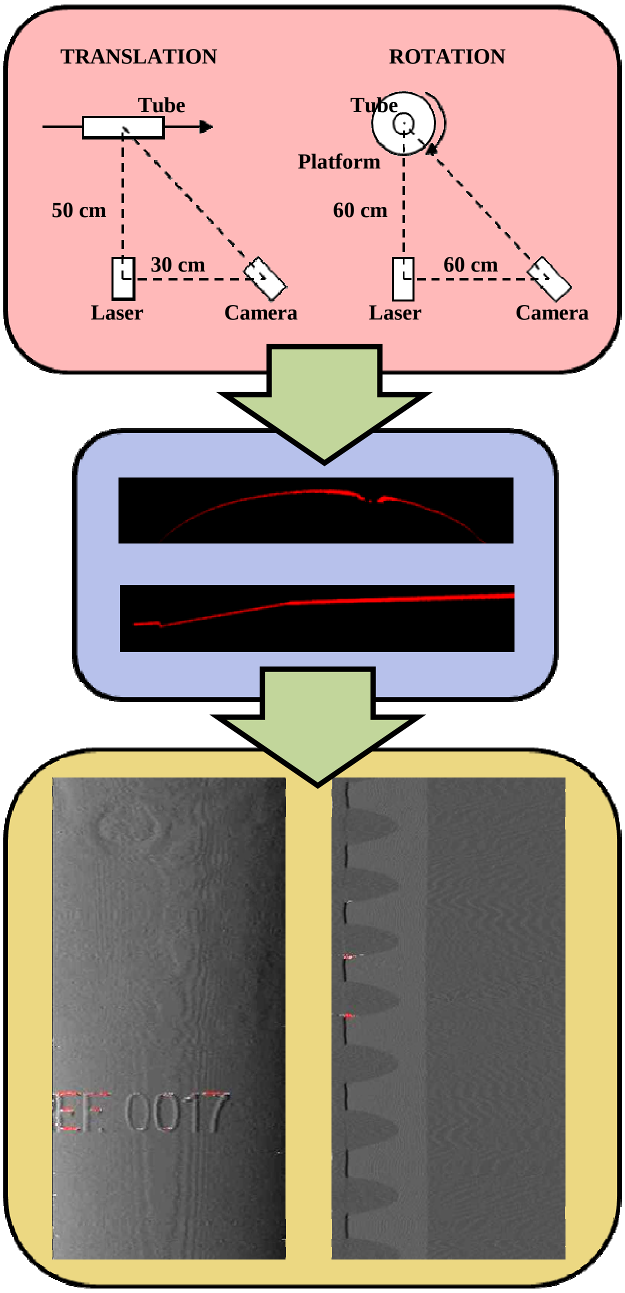

Fig. 5 From top to bottom: the translating and rotating tube system outlines, the observed laser profiles, and the obtained tube shape reconstructions for both systems.

The procedure to reconstruct tube surface shapes is shown in Fig. 6. The first task to be done is to segment the line the laser projects from the images. This can easily be done if no ambient light is used at all, as high grey-level values directly correspond to those of the laser beam. On the contrary, the red color channel would be used from RGB images in the same way.

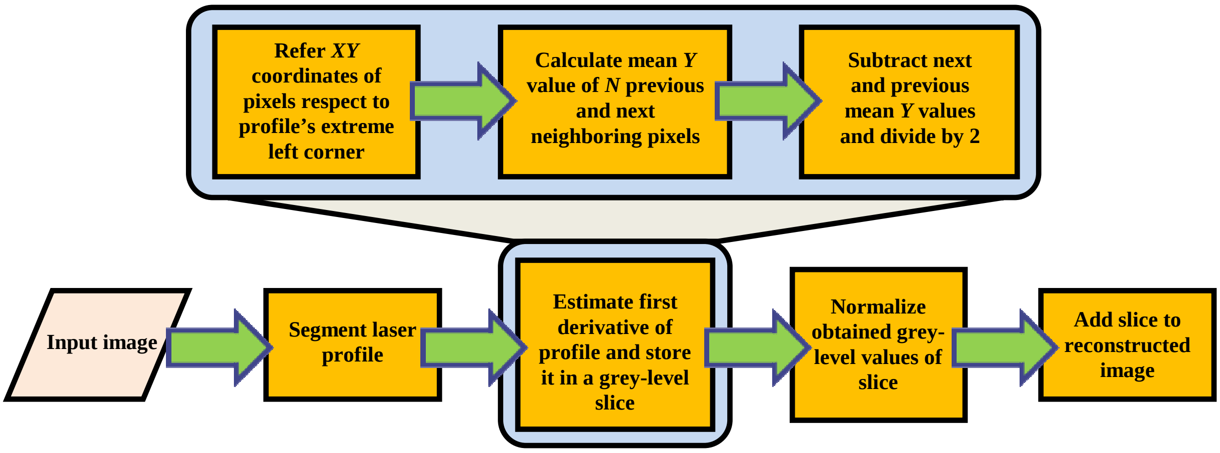

Fig. 6 Tube shape reconstruction diagram.

Next, the first derivative of the laser profile is estimated and stored in a grey-level values slice. In order to obtain a smooth profile the following three steps are applied:

1. The *XY* coordinates of the laser pixels are referred with respect to that of its extreme left one.
2. For each pixel, the mean *Y* value of the *N* previous (${}^{mean}Y_{prev}$) and also the mean *Y* value of the next *N* neighboring pixels (${}^{mean}Y_{next}$) to the current one are obtained. In our tests we have set $N = 5$, but in the extremes, only those available are used.
3. Finally, ${}^{mean}Y_{next}$ is subtracted with ${}^{mean}Y_{prev}$ and the result is divided by the difference between the previous and the next pixel *X* positions, i.e., by 2.

Afterwards, the grey-level values of the resulting slice are normalized to improve the visualization quality. This is done by rescaling the grey-level values always with the same scaling factor for all slices obtained through time. This value is determined experimentally by the user. This must be done because there can be negative derivatives, while the final grey-level values must always be positive or zero. Therefore, negative derivatives will correspond to lower grey-level values. And finally, the obtained slice is added to the image that will conform through time the tube profile.

The final reconstruction speed of the whole system depends on several factors, such as the camera's framerate, resolution, field of view, the tube's motion relative to the view, the tube's size, the laser beam characteristics, the CPU speed, the RAM memory, the programming language, etc., whose relations are not studied in this work, but it can be stated that the proposed algorithm is not computationally expensive for off-the-shelf equipment and that it leads to real-time framerates.

IV. TUBE DEFECT DETECTION

Using our reconstruction approach the detection of holes is straightforward because the laser beam in their position is not reflected in the camera. The pixels of the slice where the laser is not detected are marked in the reconstruction image as red pixels. Hence, consecutive slices presenting a hole form a red blob or connected component in the reconstruction image. Thus, these blobs are detected looking for contours in the red channel of the image, and their area is used in order to reject small red regions, which are not real holes, like those produced by the laser being occluded by the embossed letters or symbols (see the reconstruction results at the bottom of Fig. 5). Once a red cluster with a considerable area is found in the reconstructed image, it is labeled with a message alerting to its presence. This algorithm works in the same way in the translating and rotating set-ups, but in the former the resolution of the camera may be concentrated in a smaller area of the tube, so even the smallest holes can be detected.

The burr automatic detection algorithm is very similar to that of the holes (both procedures are shown in Fig. 7). In the rotating system the burrs produce an occlusion of the laser big enough to be detected as holes. The difference with respect to these comes from their shape and position, as burrs usually appear as elongated holes in the tube extremes. In principle, both burrs and holes could be simply labeled as "defects", but distinguishing explicitly between holes and burrs is interesting for statistics analyses and system parameters adjustment.

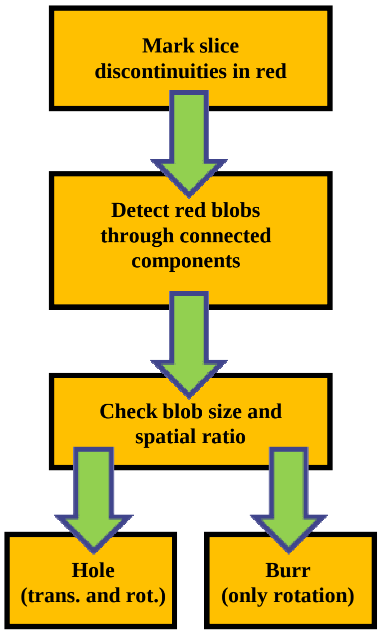

Fig. 7 Hole and burr detection procedure.

The deformations or bulges are detected with the rotating system analyzing the curvature of the laser profile over the straight parts of the tube (Fig. 8). The profile of a correct tube is presented as a straight line. On the contrary, when a deformation appears, the profile forms a curve. This way the profile pixels located out of the straight line are marked as blue pixels in the reconstruction image. Therefore, consecutive slices presenting a deformation form a blue blob or connected component in the reconstruction image.

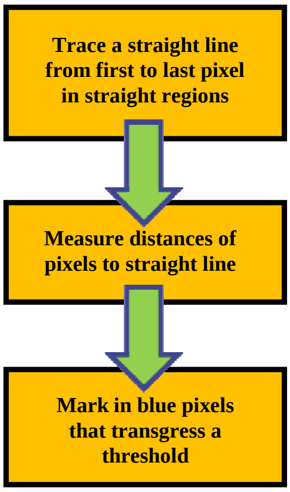

Fig. 8 Deformation detection procedure.

V. Experimental Results

The middle and bottom images of Fig. 5 show samples of observed laser profiles and resulting reconstructions for both translating and rotating tube systems. Darker grey-level values correspond to those in which the derivatives have lower values, while brighter to higher values, and therefore the reliefs of the tube surface can be appreciated. Moreover, it can be seen that the reconstructions have good enough quality even to permit reading the numbers engraved by the mold on the tube.

In Figures 9-11 three samples containing holes, a burr and deformations on reconstructed tube shapes are shown. It can be observed how the holes and burrs are correctly labeled, and the deformed regions are highlighted by the system. The shape of the shadow projected by the burr during the reconstruction is marked in red (Fig. 10), the same as the shapes of the holes (Fig. 9), which correspond to those instants in which the laser beam profile is "cut" while the tubes are being moved. It can also be observed how the aspect ratio of holes and burrs has a remarkable difference so that both types of defects can be easily distinguished from one another.

Finally, it can be observed that there are big enough areas marked in blue in Fig. 11, which correspond to those regions in which the difference between the expected shape and the measured one transgress the threshold. This piece can thus be considered as defective and consequently be rejected from the production line. It must be remarked that these detections are obtained while the piece is being scanned, so it is not really necessary to scan them completely and defective tubes can be rejected as soon as failures are detected on them.

Fig. 9 Hole automatic detection.

Fig. 10 Burr automatic detection.

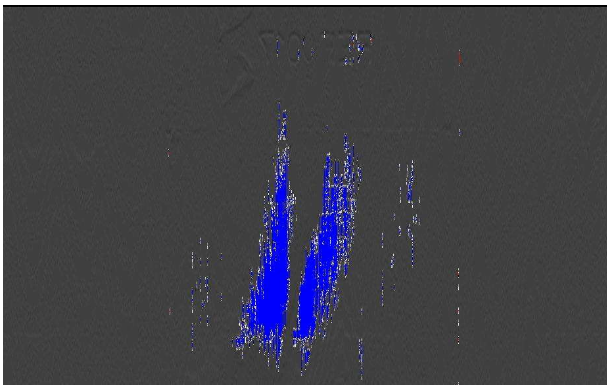

Fig. 11 Deformation automatic detection (marked in blue).

VI. Conclusion

Two system set-ups have been proposed in this work for low-cost automatic defect detection in blow-molded tubes used as outer cover of car dampers [17]. The core of both systems only requires an uncalibrated camera and a laser beam for the visual analysis of the laser beam projection shape on the tubes. No ambient illumination is needed at all.

In both systems the laser beam is set perpendicular to the tube's axis, and the camera that observes the resulting laser is set from another point of view but in the same plane. In one of the layouts the tube rotates around its axis while in the other the tube moves along it. Both system configurations can be integrated in a manufacturing line in order to automatically check the pieces quality.

Firstly, the laser beam profile is segmented, then its shape's smooth derivative is obtained, and finally it is rescaled to show the reconstructions as grey-level images. Those regions where the laser beam is not reflected are labeled as holes or burrs, depending on their position and shape. Deformations are detected in the rotating system by comparing the curvature of the laser profile over the straight parts of the tube with respect to straight lines.

Experimental results show the suitability of the proposed method to detect the mentioned defects while tubes are being scanned. The presented procedure could be integrated with the solution proposed by Picon *et al.* [26], to inspect the extreme sides of the tubes.

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