ON-LINE AUTOMATIC SELECTION OF MEASUREMENT PROCEDURES FOR DIMENSIONAL RUBBER GASKET CHARACTERISATION

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Abstract – The paper describes an image-based stereo vision measurement system for contact-less inspection in rubber gasket industry. With respect to a previously proposed system, a new dual-scale segmentation procedure is introduced, directly applicable to different classes of measurands without any software update. Furthermore, thanks to a classification stage, the proposed system can automatically activate a measurement procedure specific for each gasket, without any human intervention.

Keywords: Contact-less measurement, edge detection, automotive gaskets

1. INTRODUCTION

Machine vision has become very common in the industry in order to perform inspection tasks. An automatic system, provided with one or more cameras, image-grabbing hardware and a suitable elaboration software, can carry out on each produced piece the matching of measured linear dimensions, areas, colors or textures, with the corresponding design values and raise warnings if necessary. Vision techniques can also be successfully employed in process control applications: visual inspection results on the final products are used as inputs to a feedback network that tunes the operation of the manufacturing line in order to keep measured parameters inside design tolerances.

Authors already realized an image-based measurement system for inspection tasks within a quality assurance application in a plant producing rubber gaskets for the automotive industry [1]. A stereo vision system was designed to make the on-line contour extraction and 2D-3D reconstruction of the transversal section of some one bulb rubber gaskets, and the measurement of the main dimensional parameters. The image processing and measurement software was suitably optimized to sample the 100% of gaskets (up to 13 m/s production line speed), and provide 0.1 mm or 0.4 mm^2 standard uncertainty in linear or area measurements respectively. This performance fully matches the design specification, even if some limitations arise during the normal operation of the plant. First, when the gasket to be produced changes a human operator has to make the selection of the proper measurement software during the change-over. Then, since the contour tracking procedures and the dimensional measurement procedures are

specific for each particular gasket, new types of gasket to be produced will require new software procedures to be thought and implemented.

In the paper, after a brief description of the previous realized system, a new flexible contour extraction procedure, not specialized for a given section, is proposed. Then, a procedure for the automatic selection of the dimensional measurement set, that keeps on being still specific for each gasket, is described. Finally, experimental results are reported.

2. THE PREVIOUSLY REALIZED MEASUREMENT SYSTEM BASED ON STEREO-VISION

2.1 Hardware

The measurement station is located at the end of the line, near the conveyor belt bench (Fig. 1). It is provided with two cameras each one yielding a 2D image of the leading transversal section of the gasket at the end of the extrusion process, but each one with a different perspective angle. Two encoders measure and display the angles between the optical axis of CCD sensors and two known references on the horizontal plane, thus ensuring that the orientations of the cameras be known and reproducible. Since the surface of gaskets is dark and poorly reflecting, an illuminator lights up gasket sections in order to increase image contrast. A pair of photoelectric cells detect the presence of a gasket in front of the cameras thus triggering the image acquisition and processing via an acquisition board (PCLab-Card PCL 812 PG) held in an expansion slot of the elaboration section (500 MHz, Pentium[TM] PC). Since gaskets, due to their flexibility, do not arrive in an enough constrained position in front of
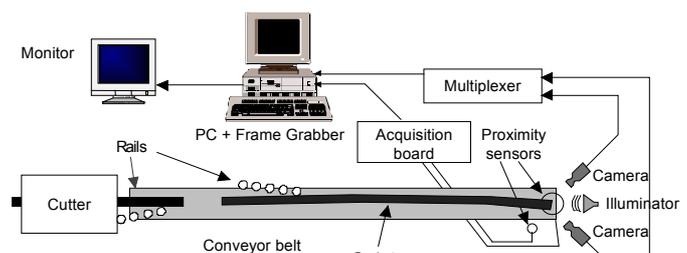

Fig. 1. The automatic measurement system

the two cameras, <u>two roller side rails</u> are employed to constrain their horizontal shift in a range compatible with the view fields of both cameras. <u>A multiplexer</u> is used to allow the <u>single frame grabber</u> to take the two images from the two cameras. The frame-grabber output is also sent to an external <u>monochrome monitor</u>, which makes operators check image quality. During the image acquisition, that lasts about 2.5 seconds, the gasket must be kept still. To this aim a programmable delay circuit switches off the conveyor belt engine, while an upstream storage unit accumulates the product drawn in the meantime.

2.2 Software

The contour extraction is realized applying a traditional edge-based segmentation algorithm, followed by an *ad hoc* routine. The well-known edge-based segmentation algorithm proposed by J.Canny [4],[5] processes each acquired image. On the obtained images a *non-maxima suppression algorithm* is applied to identify the *edges*.

A *tracking algorithm* [6] collects the edges of the image returned by the Canny operator into ordered lists. It has been suitably developed for the specific geometry of the bulb of one-bulb spongy gaskets. Different tracking algorithms were developed, one for each type of one-bulb spongy gasket, since they depend on the specific geometry of the gasket section.

Once 2D section contours have been extracted from each image, a stereo-vision algorithm builds a reconstruction of the section contours in a 3D space. The reconstruction procedure is composed of two phases:

− stereo correspondence matching, oriented to the selection of those points which are unambiguously found in both images;

− back-projection, photogrammetry relationships are then applied to every pair of corresponding new sampled points of the contours, producing the 3-D coordinates of the contours.

Finally, a measurement procedure extracts the required dimensional parameters, i.e height and width of the section, and compares them with reference design tolerances.
To this aim, at first, the 3-D coordinates of the reconstructed contour points are projected on the best-fitting plane, which includes the most of the contour points. Then, new 2-D section contours are determined as projection on the extrapolated plane, thus reducing the measurement of the dimensional parameters to a two-dimensional problem.

The measured dimensional parameters are the height (H) and the width (W) of the gasket bulb transversal section [3], as shown in Fig.2. In order to perform the quality control of gaskets, the measured values are compared with design values and their tolerance limits. Finally, the information is reported by the user interface, together with (Fig. 2):

a) the detected left and right 2-D contours;
b) the reconstructed 3-D contours;
c) the measured values of the H and W, and a message summarizing the quality test results;
d) two charts of the measured quantity in the last minutes versus time, together with the corresponding design tolerance limits and nominal values.

At the line speed of 13 m/min., the limited elaboration time allows the 100% of gasket to be measured.
All results are always expressed with a number of digits constrained into the measurement system uncertainty.

3. RUBBER GASKET SECTIONS

In order to limit the response time of the industrial plant to customer requests, each production line can be configured for different gaskets. This means that each measurement station must be able to work with different gasket sections. Furthermore, while the transversal section of gaskets gradually evolves toward different and more performing forms during its life, the fast development of new car models requires the design of new gaskets. This continuous process is hard to be followed if each minimum change in the gasket section requires a new edge detection and segmentation algorithm to be implemented. As a result the authors at first made an analysis of current products and new trends in the field, trying to define families of gasket transversal sections on the basis of few fundamental characteristics.

Generally, the gasket sections are characterized by one or more empty and soft cavities (bulbs) and a solid snap-on. In Fig. 3, some examples of contour section are reported. A criterion for an early classification of the type of section is
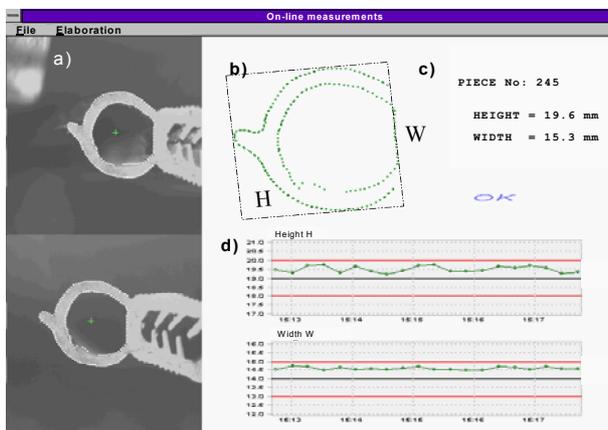

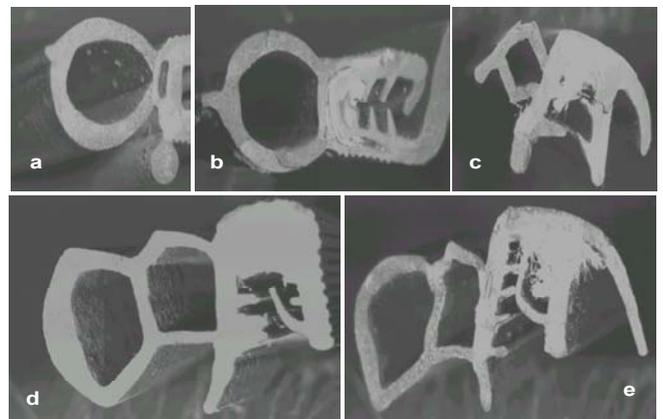Fig. 2. The output panel of the previously realized system

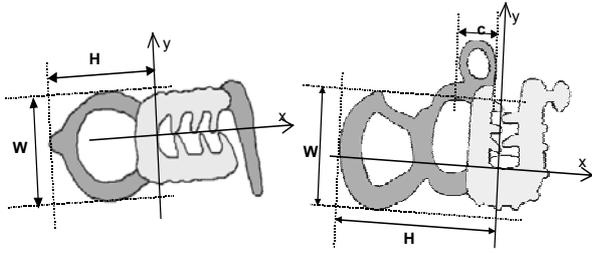Fig. 3. Examples of single-bulb gasket sections (a,b,c) and two-bulb gasket sections (d, e).

Fig. 4. Examples of different coordinate systems

Fig. 5. Block diagram of the segmentation procedure

the number of bulbs. On the other hand, the differences among sections with the same number of bulbs may be remarkable in terms of shape, number of edges, concavities, curvatures, etc. Furthermore, geometrical parameters to be measured change versus the relative position of the bulb respect to the snap-on and/or the number of bulbs (Fig. 4). This analysis raised some considerations to drive the design and realization of a new release of the image processing software: i) the number of bulbs must be detected first by the segmentation algorithm; ii) no *a priori* hypotheses have to be made about the contour shape in the contour extraction step; iii) the dimensional parameter measurement set and the reference coordinate system must be specific for each single gasket under test [2].

4. THE CONTOUR EXTRACTION PROCEDURE

The overall proposed segmentation procedure can be classified as a hybrid technique, employing both a classic edge-based algorithm and a region-based one. Actually, an edge-based segmentation technique, searching for contours as *loci* where the spatial gradient of the image intensity is maximum, is very sensitive to small size defects of the object or to the noise superimposed to the image, thus leading to false edge detection or to the introduction of gaps in edge lines. Such a problem is commonly reduced by using a spatial low-pass filter with an adequate cut-off frequency, at a price of a worse final localization of contours and, consequently, of a greater uncertainty in dimensional measurements. The basic idea underlying the proposed procedure (Fig. 5) consists in performing a good contour detection with poor localization performances on a smaller-scale copy of the acquired image, and then refining the localization by fitting these coarse contours on the edge image as yielded by an edge detection stage with a higher
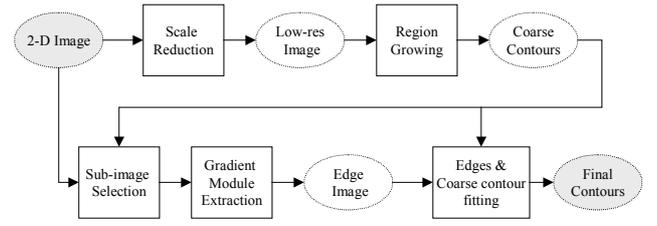
cut-off frequency.

4.1 The coarse-scale region growing procedure

At first, the acquired image (Fig.6a) goes through a histogram enhancement procedure, and, then, a coarse-resolution copy (Fig.6b) of the image is computed from the acquired image, by reducing its dimensions of a factor F=4 by averaging each FxF pixel square into a single pixel. An *ad hoc* designed region growing algorithm is applied on this copy. It recursively classifies all the image pixels in two classes: *foreground*, for pixels belonging to the section of the gasket, and *background*, otherwise. At first, two sets of *seed pixels* [4]-[5] for the two classes are built by a simple threshold procedure, then the image is scanned and each pixel is classified either into the *foreground* or into the *background* classes if it has, respectively, a *foreground* or a *background* neighbouring pixel and if its value is close enough to this neighbour (*homogeneity statement*): fixed thresholds, that were found empirically, are used with different values depending on the specific scanning direction (see Tab.I).
At the end, isolated pixels are then forced into a proper class in order to have the two classes topologically connected (Fig. 6 c). In this way, a subsequent blob-finding algorithm yields the set of contours of the image: these *coarse contours* (see Fig. 6 d) are certainly completely detected but not yet well localized.

4.2 The full-scale edge-based procedure

In order to reduce the computational burden, from this point onwards every elaboration is carried out on the sub-image extracted from the full-scale acquired image, that is bounded by the minimum rectangle enclosing the coarse contours. The image undergoes a gaussian low-pass filter, with a $\sigma=1.9$, then the module of the intensity gradient is computed (*edge image*, see Fig. 7a). The points of the coarse
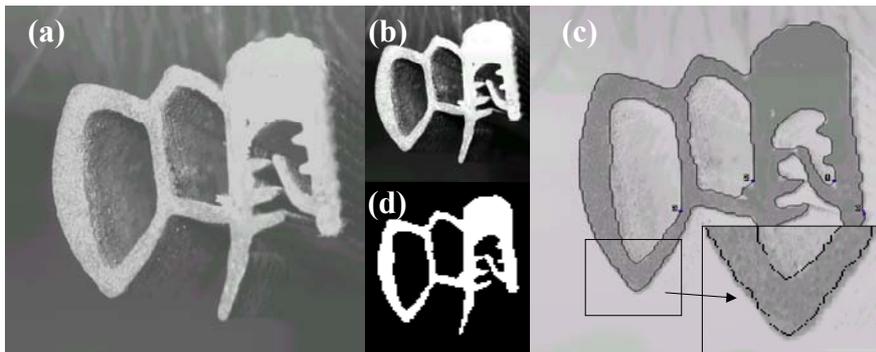

Fig. 6: The coarse region growing procedure steps

Tab. I: Values of the used thresholds (image with 256 gray levels-8 bit).

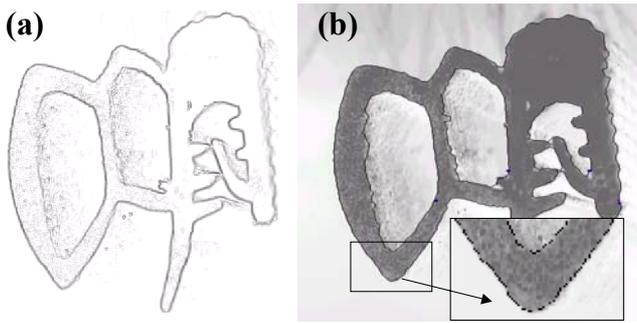|	
Background seed points	30
Foreground seed points	200
Minimum for foreground points	150
Foreground growing x, y increasing	26
Foreground growing x,y decreasing	16
Background growing xy increasing	10
Background growing x, y decreasing	8

Fig. 7. The full-scale edge-based procedure steps (in b for clearness the image is reproduced in negative)

contours are now suitably superimposed to the edge image, and each one is moved onto a local maximum of the intensity gradient, along a 2F-long segment orthogonal to the contour direction, obtaining the final contours (Fig. 7 b). In this way, with respect to a classic Canny algorithm, both the computation of the phase of the gradient and the non-maxima suppression are skipped. This assures a shorter elaboration time since the skipped computations would have been performed on all the pixels of the image, while the proposed ones are applied only on the pixels that are close to the contours. Moreover, this technique can detect contours with a sub-pixel resolution, if a suitable interpolation is used in the search for the local maxima.

5. THE AUTOMATIC SELECTION OF THE MEASUREMENT PROCEDURE

In Fig. 8 the flow chart of the selection procedure is reported. The first step is the contour structure identification. The contours are organized into a set of contour lines. For each contour line, some parameters are gathered: the length, the centroid and the position and dimensions of the "enclosing" rectangle, *i.e.* the smallest rectangle that encloses that contour (see Fig. 9). Using these parameters, each contour line is labeled either as the external contour or as one of the internal contours. The results of this classification, and the number of the detected internal contours in particular, will be used in the pattern matching phase.

The following processing is based on the consideration that the shape of the external contour of the gasket, and in particular its curvature, carries enough information to separate different sections. The curvature of the contour is defined as $c(s) = d\varphi(s)/ds$, where s is the curvilinear abscissa along the contour, and $\varphi(s)$ is the angle of the tangent with respect to a reference direction. A pattern is extracted as the set of the local extrema of the curvature ("*critical points*", [6]), after some simple regularizations: *e.g* two extrema that are very close are merged into a single point (see Fig. 10).

A template-matching algorithm finds the best match between this observed pattern and the reference templates stored in a database. An early classification is made using the detected number of internal contours: a pattern extracted from a two-bulb gasket, for example, is compared only with

two-bulb templates. The templates are patterns extracted in the same way as the observed patterns; moreover, a single gasket section may have more than one template in the database, allowing to consider more possible views (*i.e.* for different perspective angle or different view fields), see Fig. 11. The template database has to be updated when the
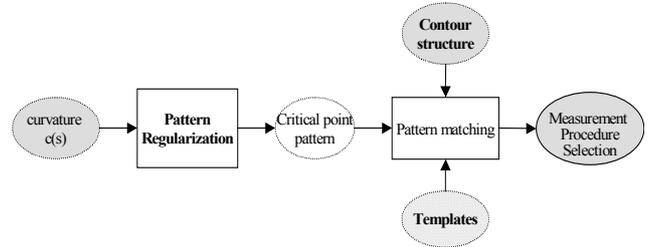

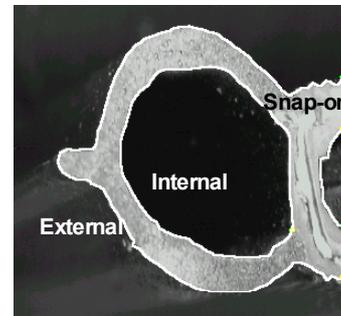Fig. 8. The automatic selection of the measurement procedure

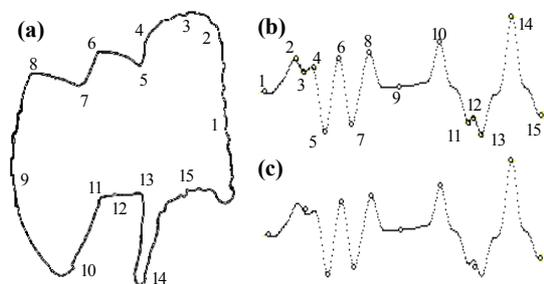
Fig. 9. Example of contour structure identification

Fig. 10 (a) Gasket excternal contour with critical points, (b) contour curvature, (c) contour curvature after the regularization
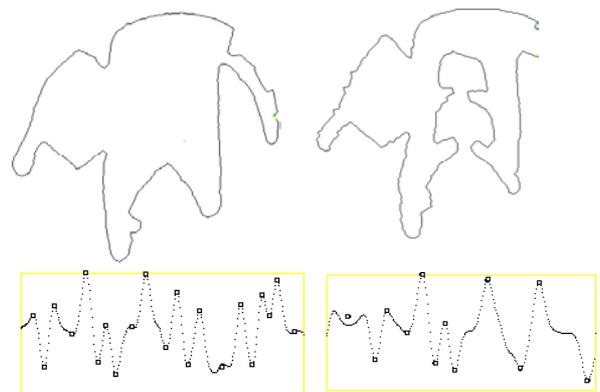

Fig. 11. Different views of the same gasket and the corresponding templates

manufacturing line starts producing a new type of gasket for the first time.

The goodness of the matching is reported in terms of a cost function f, evaluated as a distance between the observed and the template patterns; furthermore, when the dimensions of the two patterns, N_1 and N_2, are different, the cost function is increased of a constant value q for each point that does not match:

$$f = \frac{1}{N_O}\sum_{i=1}^{N_O}d_i + (N_1 - N_2)\cdot q$$

where $N_O = min\{N_1,N_2\}$ and d_i is the Euclidean distance between the matching points of the *i-th* pair. At the end of the template-matching procedure, the system runs the measurement software that is associated with the section whose template gave the minimum cost function.

The template database has to be updated whenever the manufacturing line starts producing a new type of gasket for the first time. In this way the realized software is very flexible and extensible.

6. EXPERIMENTAL RESULTS

At first, the performance of the measurement system in terms of elaboration time are evaluated, in order to verify wheather the good time performance of the previous system, that allows the 100% of gasket to be measured, are still valid. The new contour extraction procedure is executed in 53% of the time required for the previous one, and the classification procedure requires less than 1% of the whole procedure. As a consequence the new system is fully compatible, in terms of time performance with the previous one.

Then an experimental characterization of the system is carried out with reference to both contour extraction procedure and automatic measurement selection, with reference to the different kinds of gaskets and in different operating conditions.

6.1 The contour extraction procedure

In the evaluation of the performance of a contour tracking algorithm, it is hard to find quantitative parameters that could be significant in order to compare different systems. In Fig. 12, a summary of the good results of the contour extraction procedure is reported: the procedure is run on the same images of Fig. 3. As you can see, although the wide variety of profiles, the procedure is able to locate the contours with a good accuracy. Other tests were carried out in comparison with the old contour procedure. These tests showed that the new algorithm is able to track the same contours detected by the previous system, at least for those images that can be analyzed by the previous system. Moreover, the new system has proved to be more robust in case of more noisy and less clear images. As an example, Fig. 13 shows a comparison with the previous tracking algorithm: the previous system do not complete the contour tracking due to gaps in the edge lines, while the new system does. Eventually, in Fig. 14 the results for two cases with blurred or corrupted images are reported. As you can see,

the procedure is able to give at least approximate gasket contours, while the previous system did not give any result in these cases.
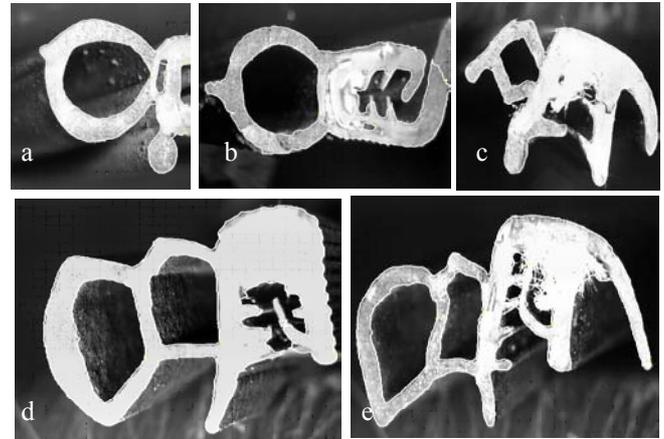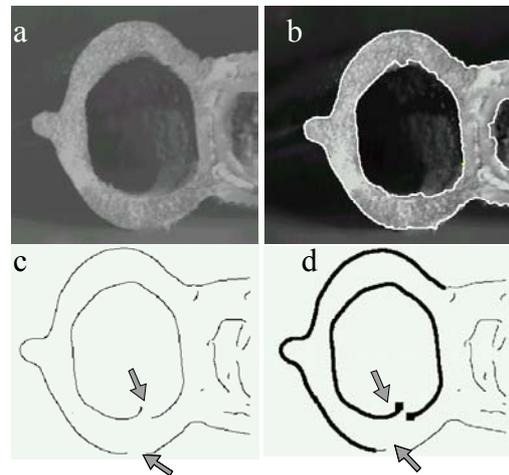

Fig. 12. Examples of extracted contours

Fig. 13. Comparison between the previous and the new contour tracking algorithm: a) acquired image; b) contours extracted by the new algorithm; c) edge image (Canny); d) incomplete contours as extracted by the previous system.
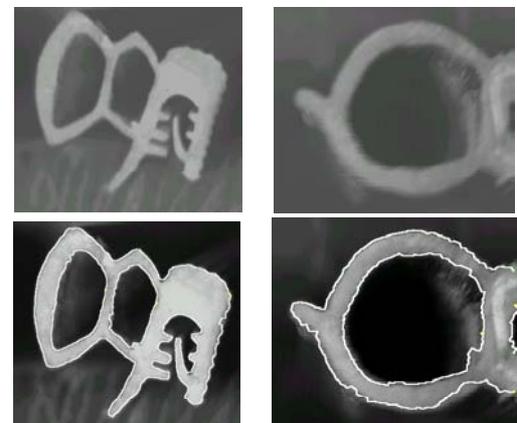

Fig. 14. Examples of contours extracted from blurred (left) or corrupted images (right)

6.2 The classification procedure

A 99% of correct classification was achieved in tests carried out in 5 hours of continuous operation of the production line per each gasket type. This very high percentage of success of the classification procedure is due to the robustness of the approach based on a stereo vision: both left and right images are processed by the same algorithm and in case of disagreement between the classification results a missed classification warning is raised by the system. Fig.15 shows an example of the operation of the classification procedure: the external contours and the patterns of critical points superimposed on the curvature of the external contour are plotted both for the analyzed section, a) and b), and for the best matching template, c) and d). In Fig.15(d) the analyzed pattern (round dots) and the template (square dots) are plotted together, showing the closeness between the couples of critical points. In Fig.16 an example of mistake occurred in the classification is shown: the best matching template (square dots) belongs to a different gasket section class.
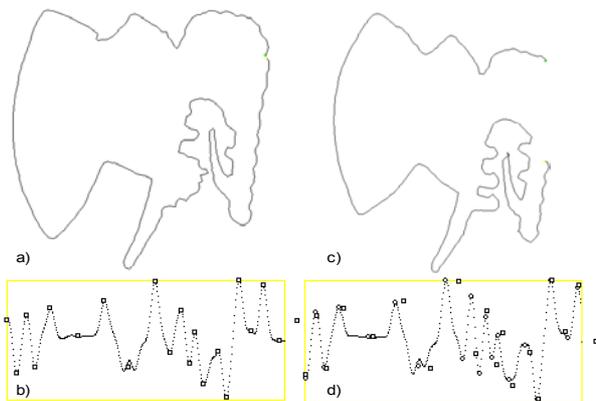

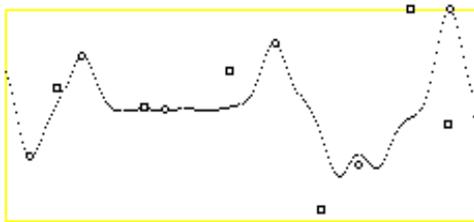Fig. 15. An example of correct section classification. See text for details.

Fig. 16. An example of mistake in the section classification.

7. CONCLUSIONS

An image processing-based measurement procedure for the dimensional analysis of the transversal section of automotive gaskets, has been proposed in the paper. It has been developed within a common research program carried out by Metzeler Profile Systems Italy and the University of Salerno aiming to the automation of the manufacturing process of rubber gaskets. The new measurement procedure integrates a general purpose differential edge detector with a suitably arranged region growing technique and a template matching procedure in order to achieve maximum flexibility versus contour shape and number of bulbs characterizing the transversal section of gaskets. With respect to a previous proposed version the new image processing software seems to be self-adaptive within a very larger work field including also multi-bulb sections, less burdensome and more robust versus image noise and imperfect focusing. On the other hand the measurement software keeps on being gasket specific due to the different coordinate systems adopted by gasket designers in drawing measurements quotes. Finally experimental results highlighted that the self-adaptive behavior has been achieved together with a high sensitivity in detecting imperfection of the gasket section respect to nominal parameters.

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