Automatic Quality Control of Industrial Products for Irrigation

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Abstract

This paper describes the analysis method we used in the E.C. ESPRIT technology transfer project VIPLAST_2 for the detection of defects in industrial plastic components for automatic drop irrigation.

The analysis process verifies that the design rules of prism-shaped drippers are met before they are soldered at a regular distance within a drop pipe and afterwards it points out missing or misplaced holes drilled on the pipe surface overlapping the dripper.

Our method faces problems arising from the visual features of the object material, such as highly reflective surface and absence of texture, and handles variable lighting conditions and unstable object positioning namely overturning, jitter and rotation.

Experimental results on the industrial production lines are given. They show the reliability of our method, obtaining a very high rate of detected defects and a low rate of false alarms. The company real time inspection requirements are also met.

1. Introduction

The VIPLAST_2 project was promoted by SIPLAST S.p.A., a company of plastics components for drop irrigation, and has been developed in co-operation with IFCAI-CNR as scientific partner and Easy Integrazione di Sistemi S.r.l. as system integrator. Aim of the project was to detect and to point out the main defects possibly affecting *flat drippers* and *flat pipes* at production time.

Flat drippers are thin plastic components shaped as prisms 36(w) $\times$ 10(h) $\times$ 2(d) mm. They are soldered to the inner surface of the drop pipes and are responsible for controlling water outflow (see Fig.1).

Water flows inside the pipe and crosses the dripper wall through a filter made up of a set of holes grouped to form a regular grid. Then water reaches the cavity between the outer surface of the dripper and the inner surface of the pipe, then flows along a labyrinth path hollowed out on the outer surface of the dripper. Finally it leaves the pipe through one hole pierced on the pipe surface in correspondence of a flat square *platform* at labyrinth end.

Drippers are made of moulded plastics, uniformly blue light coloured and their surface is smooth and moderately reflective. Main meaningful defects are badly shaped filters because holes are merged or occluded and badly shaped drippers because of burrs or missing of material.

Pipes are thin cylinders (thickness: 0.2 $\div$ 0.8 mm, diameter: 17 mm) made of black plastics and their surface is curved, rough and highly reflective. During production they are pressed, shrinking their cross section in order to obtain a product easier to be packaged and handled. During usage, hydraulic pressure inflates the pipe; water flows inside it and drops out through the holes drilled on its surface. Main meaningful pipe defects are missing or misplaced holes.

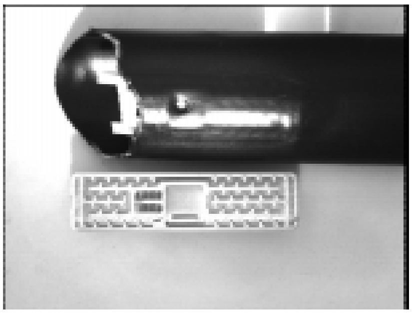

Figure 1. A flat dripper and a flat pipe cut to show dripper positioning.

Quality control cuts production costs and improves the company image. It decreases the amount of defective components that need to be collected and fused again as well as the amount of goods returned by the customers.

Before the company quality assurance plan was started the dripper inspection process was based on off-line human visual control on statistically chosen samples and pipe visual human control was performed on snapshots of pipe holes continuously displayed on a monitor. The procedure resulted boring, tiring and somewhat unreliable because of high production rates (2 drippers/holes per second).

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The requirement to perform total quality control even at high production rate and to lower the discretion of the operator yielded the need to automate the control.

Tests performed by the industrial partner on some commercially available vision systems of moderate cost [1-2] resulted unsatisfactory. Tested systems used a single illumination source and vision algorithms were based on segmentation of image areas through grey level thresholding. Binary or grey-level template matching was used to infer presence of patterns in areas selected during the calibration phase. No test was available to check for unexpected small patterns as burrs or holes randomly positioned.

In our case single source scene illumination is inappropriate because plastic surface reflection lowers contrast between object and background or saturates camera response. Shadows around 3D object contours due to non planar or non uniform lighting and to light scattering make simple grey-level thresholding unreliable. In particular shadows around dripper holes, which are quite near and hollowed with respect to the dripper surface, may mask dripper separation.

2. Lighting and acquisition details

An illumination system was designed and its configuration was optimised to enhance the contrast among the plastic material and the background and to control reflections and shadows.

Dripper analysis concerns detection of missing or excess of material, so it is important to reduce shadows around hole, which can mask hole separation.

In the final asset, drippers stream under the vision system in groups of four on a circular conveyor disk, spaced in slots. Drippers appear in the camera view field as *bright* objects against a *dark* background. They are illuminated sideways by two linear flashing lamps with beam axis at an angle close to 23 degrees from the normal to the conveyor disk plane.

This configuration minimises stray and reflected light entering the camera, and reduces shading being generated around labyrinth edges. It also limits the intensity of direct light reaching the bottom of filter holes, so that the background remains evident through the holes (see Fig.2).

Pipe analysis concerns, instead, detection of presence and correctness of the position of each hole drilled on the pipe surface. The right position of the hole is in correspondence of a flat square *platform* hollowed on the dripper surface.

The problems to deal with are the absence of direct visual evidence of structures of the dripper shape and the great variability of the luminance pattern due to reflections on the pipe surface made rough by the underlying dripper. This pattern changes image by image, above all when the flattening of pipe, the position of the inner dripper or the external lighting conditions change.

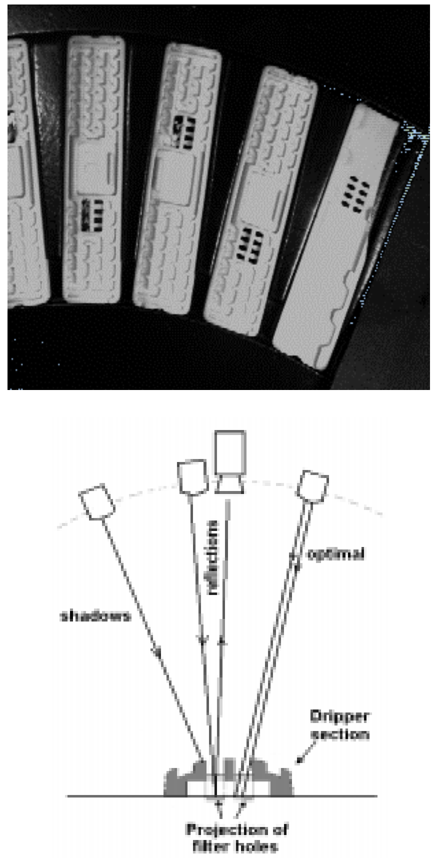

Figure 2. Grey level image of defective drippers and illumination geometry.

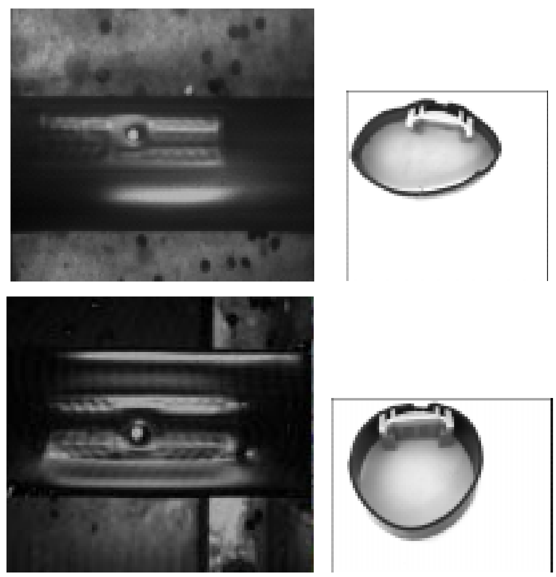

Figure 3. *Left column*: pipe images showing different reflections on the pipe surface. *Right column*: cross pipe sections showing different positions of the inner dripper and different pipe curvatures.

Visual evidence of pipe hole is granted if the contrast between the pipe surface and the dripper surface visible through the hole is properly highlighted. Visual evidence of dripper position is given by a cluster of bright blobs due to light scatter and reflection on pipe surface deformed by the underlying dripper. Other bright stripes parallel to pipe axis can appear as a result of reflection of light sources. Their shape change according to pipe surface curvature (see Fig.3).

The configuration of the designed illumination system was optimised to enhance the contrast between the darkness of the pipe surface and the brightness of the spots (see Fig.4).

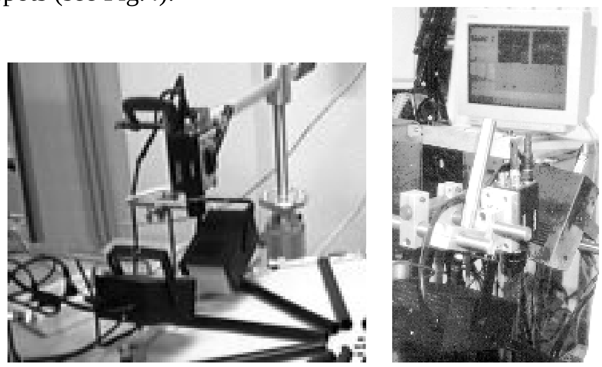

Figure 4. The lighting system arranged for in-lab simulation of the production line (*on the left*) and for on field operation (*on the right*).

Pipe is supposed to move under the camera as a dark continuous object, illuminated sideways by two flashing lights synchronised, to obtain views centred on the expected positions of holes. The flash inclination is properly calibrated to force a *bright* spot and a well defined *bright* reflection pattern on the pipe surface, concave towards the hole, including a *dark* ring extending sideways in two stripes. Both pipe curvature and radial dripper position influence the symmetry of the pattern and the separation among the stripes.

Dripper and pipe images are acquired at a quarter of TV-PAL resolution (384x288 pixels) to obtain a pixel size of about 0.2 mm.

A typical dimensions set is shown in the following table (units in pixel):

Dripper area	50×180
Filter area	18×22
Filter hole area	7×4
Filter hole separator	2
Drilled hole diameter	12
Platform area	30×30

The vision task [3] is accomplished by two different modules, *dripper-analysis* and *pipe-analysis,* while a *calibration* procedure is devoted to tune analysis parameters.

3. The dripper analysis module

The inspection process analyses images of four drippers a time and outputs results concerning the status of each dripper and a symbolic description of the detected defects.

Dripper scene layout is manifold because they may appear in the image upside-down, with filter in the upper or lower dripper half and their position is subject to jitter.

The dripper analysis module uses chromatic segmentation to split image into meaningful basic objects and design rules to merge them into complex objects, to reconstruct and to interpret the scene.

Firstly the dripper image is segmented using grey levels and edges to label chromatically homogeneous dark and bright components of meaningful size. Components with appropriate values of area, elongation, position and chromatic label become candidates to basic scene objects (dripper and filter holes). A relaxation step refines segmentation in shadow areas close to the edges, as described in section 5.

After the segmentation, components are aggregated according to the scene design rules (filter structure and position). Small dark components are clustered to identify filters and the latter are associated to the nearest big bright component to complete dripper reconstruction.

Filters with an insufficient number of correctly sized holes are labelled as occluded.

Components not recognised as basic or complex objects are interpreted as defects and labelled accordingly. Very small components are considered as noise and discarded, non-clustered dark components are signalled as unwanted holes, and undersized bright components as defectively small drippers.

The detection of dripper shape deformation due to lack or excess of material (burrs) requires more processing.

Firstly image is aligned to correct global image rotational and translational jitter due to conveyor mechanical tolerance for the dripper positions. Alignment is performed by identifying two reference markers drawn on the conveyor in known positions and applying to image the roto-translation required to move markers to the reference position. Then each dripper position is corrected for jitter inside the conveyor slot by shifting filter centroid to the expected position.

Shape test is then performed through matching with a dripper template oriented in one of the eight possible poses (*up* or *down* filter pose for each of the four possible angles) stored during the calibration phase.

Dripper areas not matching the template are considered as burrs. Template areas not matching the dripper are considered as lack of material.

The city-block transform norm [4] is used as a metric to weight the contribution of regions far from template outline to the overall measure of shape deviation from the reference.

4. The pipe analysis module

The procedure for pipe analysis identifies the bright component due to dripper seen through the hole drilled in the pipe. It also verifies hole area, shape and position relative to the underlying dripper. Evidence of dripper extension under the pipe surface is given by variations of the reflection pattern on the pipe relief.

The pipe image is firstly chromatically segmented into a dark region corresponding to pipe and other bright regions corresponding to hole and reflection patterns, using the same procedure described for dripper analysis.

The right position of the hole is in correspondence of the underlying dripper platform. The reflection pattern doesn't reproduce the exact platform shape but it appears concave in correspondence of it, thus key points are searched on the concavity to evaluate the hole position.

In a well-calibrated lighting asset the reflection components are separated by a dark stripe surrounding the pipe hole spot. The lower/upper contours of the component above/below the hole are extracted and compared with two analytic templates. The expected curvature is piece-wise approximated by two segments connected by an ellipse (see algorithm details below). The co-ordinates of best match are searched using a least square method, moving the template inside a rectangular window dimensioned during the calibration phase.

New positions of four key points chosen on the analytic template are used to bound the tolerance region acceptable for hole position.

5. Algorithm details

5.1. Dripper analysis

To increase the algorithm robustness and to speed up the computation, four Regions Of Interest (ROI) are selected during the calibration phase: the meaningful *image-region*, the *dripper*, the *platform* and finally the *hole* ROI.

Chromatic histogram segmentation [5] is performed on the *image region*. Histogram maxima are evaluated and a couple of them are identified as representative of *dark* and *bright* chromatic components using bound levels appropriately set during the calibration phase. Pixels with grey levels in the region immediately around the minimum between the two peaks are assigned to the chromatic component *grey*; the remaining ones are attributed to components *dark* and *bright.* Fig.5 shows the segmented histogram overlapping the labelled resulting image.

Also image region pixels featured by sudden grey level change and detected by the Laplacian operator [6] are assigned to the *grey* component.

Region-growing with relaxation is used to incorporate *grey* pixels into *dark* and *bright* regions.

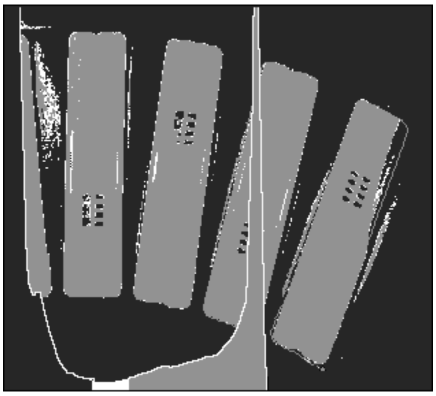

Figure 5. Segmentation of the chromatic histogram overlapping the resulting labelled image.

Firstly strong edges are evaluated on the grey level image using the zero crossing of Difference of Gaussian operator [6]. Grey pixels are then iteratively relabelled with the label of the *dark* or *bright* pixel in their neighbourhood having minimum difference in grey level. During first iteration cycle the growth is stopped when it reaches an edge. During the second iteration cycle also grey pixels on edges and their neighbours are reassigned. The two step procedure smooths the dependence of the relaxation method from pure geometrical effects.

A list of descriptors of connected components of meaningful size present in the chromatically labelled image is then created. An identifier is assigned to each component and the following features are evaluated: area, bounding box, centroid co-ordinates, offset relative to image origin.

Dark components having area comparable to the extension of the *hole region* are identified and eight of them, having centroids nearest to the possible positions of filter centres are selected as cluster seeds. Hole candidates are grouped in clusters of radius comparable with the dimension of the *filter region* (see Fig.6).

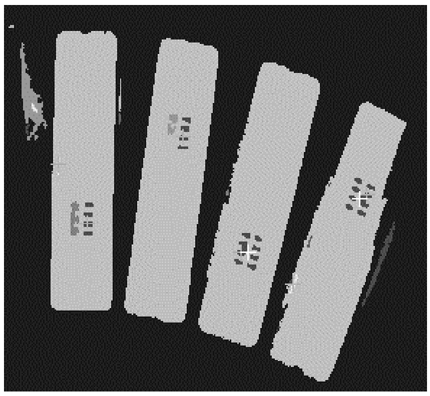

Figure 6. Filter hole clustering: holes belonging to the same cluster have same colour, as shown in the last two drippers.

Bright components with area comparable to the extension of the *dripper region* are identified and each hole cluster is associated to a dripper candidate component. Association is made by searching for the minimum distance among measured and expected filter centres.

Dripper shape analysis is performed on dripper boundaries by matching each dripper with the appropriate template. Masks of dripper in each of the eight possible dripper poses are acquired and registered during calibration.

The city block transform operator is applied to dripper template masks and to surrounding background to obtain a shape map with pixels labelled with distance from template outline.

The eso-transform values give distance weights for dripper areas not matching the template (burrs). The endo-transform values give distance weights for template areas not matching the dripper (lack of material) (see Fig.7).

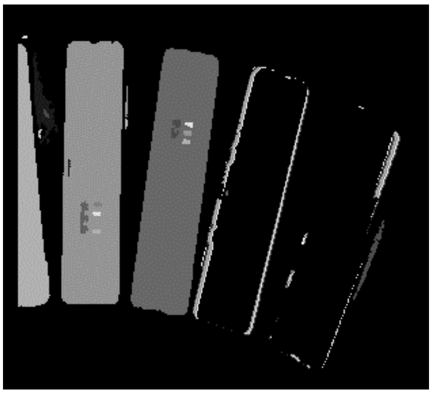

Figure 7. Dripper defect labelling: filter holes of the first two drippers are differently coloured because defective (merged and occluded holes). Oversized dimension of the third dripper is highlighted through the coloured boundary. The lack of material in the last dripper is pointed out through the coloured areas inside the expected dripper boundary.

5.2. Pipe analysis

The procedure employs ROIs definitions and thresholds equivalent to ones used by the *dripper-analysis*.

The pipe image is chromatically segmented by the algorithm above described in order to obtain dark and bright regions and a list of connected components.

The bright region includes the hole spot and other areas due to reflection on the pipe surface relieved by the underlying dripper. The major component is shaped as a double opposite *bean*. In a well-calibrated lighting asset the pipe hole spot between the *beans* is separated from them by a dark ring. So the presence of the reflection pattern which affects the inspection process, has been turned into an advantage to check the position of the hole as described below.

Bright components lying inside the *platform-region* are evaluated as hole candidates. The component having minimum distance in feature space from values expected for area, circular shape and position is selected as pipe hole.

The reflection pattern concavity is the only visual reference available to evaluate a reasonable tolerance area for hole centre. So key points are searched on the reflection pattern outline, namely on its concave part, as evidence of platform boundaries. The expected curvature of the reflection pattern on both sides of the pipe hole is piece-wise approximated by two segments connected by an arc of ellipse, whose parameters are derived from dimensions of the platform ROI set during calibration and two key curvature points are marked on each template curve (see Fig.8a).

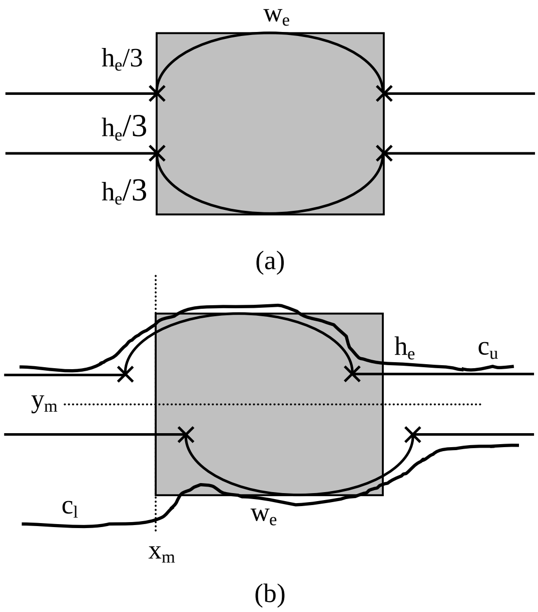

Figure 8. Piece-wise approximation of the reflection pattern: w_e and h_e are the expected width and height of platform ROI; y_m is the measured ordinate of the centre of platform ROI and x_m is its left side abscissa; c_l and c_u are the lower and upper contours of the reflection pattern.

The templates are separately moved in a bidimensional window until the minimum distance from the reflection pattern border is found. The 4 key points are then used to evaluate a bounding rectangle for the hole centre position (see Fig.8b).

Finally results are evaluated to signal possible defects, if any. Absence of the hole or distance from the centre of *platform area* greater than a maximum permitted value is signalled as *missing-hole*. Distance between hole centroid and *beans* component centroid greater than a defined threshold is signalled as *misplaced-hole* (see Fig.9).

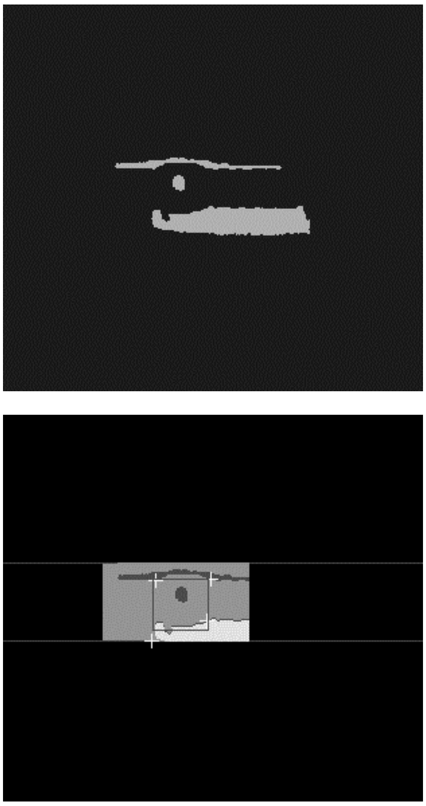

Figure 9. *Top:* Chromatic regions after *region growing* operator. *Bottom*: The square area represents the measured *tolerance region* for the hole position. The inner component represents the detected hole.

6. Experimental results

The quality control procedure has been entirely developed on a Solaris platform in the Motif graphics environment, in order to support in-lab simulations at IFCAI. The on-field release was instead implemented on a Windows NT platform in order to minimise system cost.

A friendly Graphical User Interface was developed by EASY in the Microsoft Visual C++ Development Environment to support easy package tailoring to a variable geometric and lighting asset.

The final prototype, presently under test on two SIPLAST lines, operates in real time, synchronised with the production lines and performs analysis of dripper views (4 drippers per image) at a maximum rate of 1.5 images per second, on a 300 MHz Pentium II based platform. Pipe analysis can operate, instead, at a maximum rate of 8 single pipe views per second.

Table 1 shows the results of the first performance test made on field. If the illumination asset is guaranteed almost any defect is revealed and a moderately low rate of false alarms is signalled.

Work is in progress to reduce, on the dripper line, the rotational jitter on the conveyor disk that limits the precision of the shape-matching algorithm.

On the pipe production line, the major weakness still remaining is the reliance of the detection algorithm on the shape of the reflection pattern, depending on the dripper insertion angle. Work is in progress to introduce pattern self-learning in the calibration module.

DRIPPER	***Detected (%)***
Good	97
Bad size	98
Small holes	99
Partial occlusion	95
Total occlusion	98
Moderate deform *(< 0.5 mm)*	94
Deform *(≥ 0.5 mm)*	99

PIPE	***Detected (%)***
Good	94
Partially drilled hole	85
Hole occluded by shavings	98
Missing hole	90
Misplaced hole *(± 0.5 mm)*	97

Table 1. Success rates in dripper and pipe cases.

Acknowledgements

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