Automated Visual Inspection System (AVI) for crankshaft production processes

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Abstract

The paper describes an Automated Visual Inspection -AVI- System embedded in the control of the production process of complex mechanical pieces. This implies integration of NDT systems (Automated Visual Inspection system, Optical Roughness assessment system and Laser measurement system, performing over CAD data from pieces), quality assessment system, production process's assessment system and tracking system.

1. Integral Quality Control.

Complex mechanical parts (like engine crankshafts, turbine axes, precision shafts or bearings), later attached to complex machines (trucks, ships, aircraft, cars, power generation turbines, etc.), are produced following a step-by-step process that usually, and depending on the piece complexity, lasts for hours.

Critical aspects of this process are: ***presence of surface defects*** *due to fails during machining process*, ***irregularities in external dimensions*** *due to malfunction of machining cells,* ***excess of surface roughness*** *due to fail in surface treatment processes,* ***high response time when correcting process parameters*** *what produces great scraps and* ***practical impossibility to follow parts*** *during their useful life.*

The global system in which the AVI system is integrated pursuits the on-line inspection, quality control, production process assessment and tracking of mechanical parts with complex shape.

Several problems arise [1] when attempting an automation as the one described, mainly for the following reasons:

Piece tolerances measurement

Actually [2], most dimensional control is perform by means of touche probe and pneumatic techniques which make impossible an accurate correlation between product conditions and process status, since detected faults are ambiguous regarding the production step where produced.

Even when applying high precision triangulation sensors have small standoff, and maximum precision rounds 5µm for 1 meter extent part.

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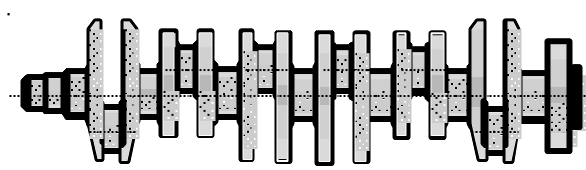


Fig. 1. Crankshaft.

Surface defects identification:

Due to 0.1mm resolution needs, actual visual inspection processes [3][4] perform slowly, being a bottle neck in machining production processes for mechanical parts. Although where artificial vision is applied, decision about defects type and importance fails on human operator to assure reliability and frequently this produces erratic inspection.

Surface roughness determination:

Actually [5], surface roughness measurement is performed on laboratory basis only over a very small sample of production (1%) due to lack of reliability of present systems when incorporated to on-line work.

Process assessment feasibility:

Due to the high complexity of production process, the high distribution of process knowledge among operators and the disparity of this knowledge (material selection, heat treatment processes, machining processes, surface treatment processes, quality processes) on-line control is not reliable, nor objective.

Parts tracking availability:

Not reliable wide-range [6] tracking systems apply for the production process improvement of mechanical parts in the sense that feed-back over the production process is very small while the parts is being manufactured, there is no effective feed-back when problems arise once the part has been mounted on the destination machine/car/truck, and request of precise information over every individual part by users/repairing services to producers, is an almost impossible task. Figure 2 shows the complete SMARTMEC scheme, where it can be observed:

- Working Cells. These include the AVI System, the laser-based measurement system and the surface's roughness measurement system.
- QUAL System. Responsible for overall quality assessment of every produced part and for piece's scheduling.
- PAS System. Responsible for generation corrective actions over the production process when malfunction is detected.
- TRACS System. Responsible for piece's tracking during the production process. Also performance qualities achieve piece's tracking once they are attached to mechanical sets (troubles, repairs, ...).

2 Automated Visual Inspection Task.

Within this integral quality assurance system called SMARTMEC, a key point is the Visual inspection of every produced piece [7]. Requirements for visual inspection include :

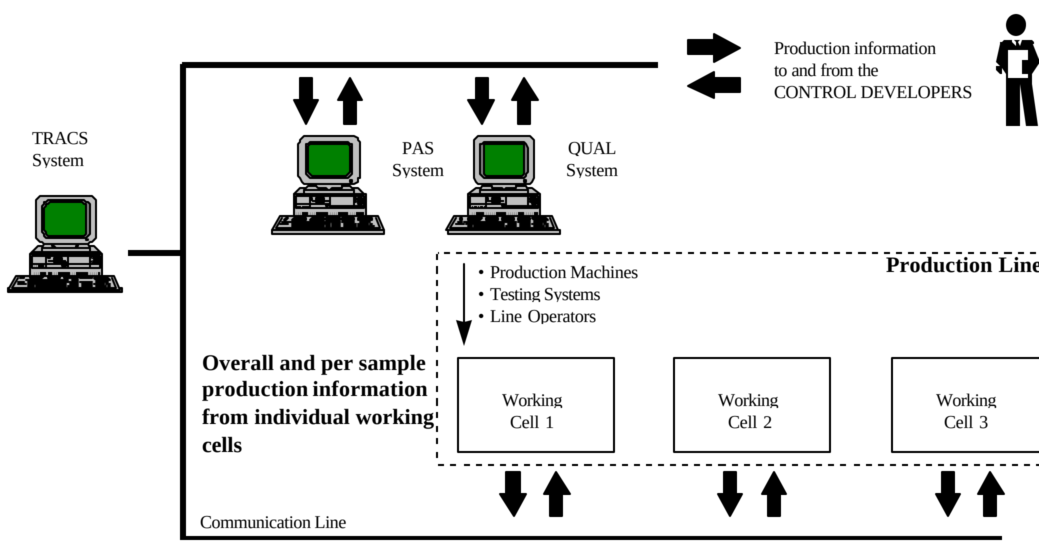


Figure 2. SMARTMEC System.

Integral Inspection demanded. Inspection for surface visual defects, lacks in mechanisation, presence of waste material after mechanisation and absence of mechanical operations:

- Detection and recognition of blows produced by knocks. Their visual appearance is a change in the intensity of reflected light, more detectable as the knock becomes deeper.
- Detection and recognition of stripes. The visual appearance of stripes consists of faint lines following the piece's curvature with an alternance between clear and dark effect.
- Detection and recognition of lacks.Lacks are observed as a combination brilliant/dark produced by change in the angle of reflected light.
- Detection and recognition of pores and fissures. Fissures show the appearance of very slight straight lines perpendicular to piece's curvature.
- Detection and recognition of inclusions. Inclusions can be observed as dark speckles with different shape within the mechanised area.
- Detection and recognition of presence of waste materials. Waste materials can be recognised as dark speckles with different shape outside the mechanised area.
- Detection and recognition of absence of some mechanical operation over the piece: absence of drills for oil circulation, keyway (lodging of cotter), etc. Observed images do not match with expected pattern.
- Detection of changes in chamfered surface planarity. Visual recognition of changes in planarity can be observed by slightly variations in light map reflected by the steel surface.

Inspection rate: up to 12 crankshafts/hour. (crankshaft is the more complex piece).

High resolution: typical defect's size of 0.1 mm width for fissures.

Flexibility demand: high flexibility adapted to a big variety of pieces produced in a workshop.

3 The AVI System.

To achieve the above mentioned requirements, the developed AVI System is formed up by:

Mechanical supporting System (MSS). Its aim is to move the inspection units along the piece's shape. To assure flexibility -one main requirement- a 6 dof robot has been adopted. Automatic tool changing is provided for operation with different NDT sets.

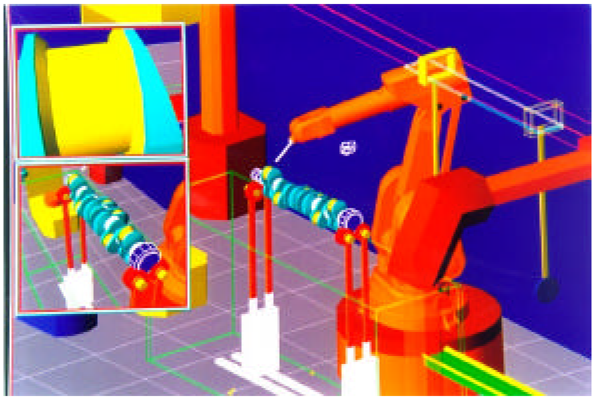
Image Acquisition Unit (IAU). Due to the high resolution demand an special optical system has been developed that leads both light to piece's surface and image from piece's surface with .6 ηm concentric fibres.

Image processing Unit (IPU). On-line performance of the AVI system is assured by using high performance image processing units based on the powerful multi-processor DSP TI TMS320C80.

Master unit (MU). The overall supervision and intelligence of the AVI system relies on the Master Unit. It is responsible for AVI system interfaces with the Control Unit , the human operator and the production process. The MU generates inspection strategies as a result of inspected product and requirement from the operator. Also, the MU hosts a classifier, to decide the quality of the inspected part.

4 The Visual Inspection Cell.

Illustration 1 shows the cell where visual inspection takes place.



Illustr. 1. AVI Cell.

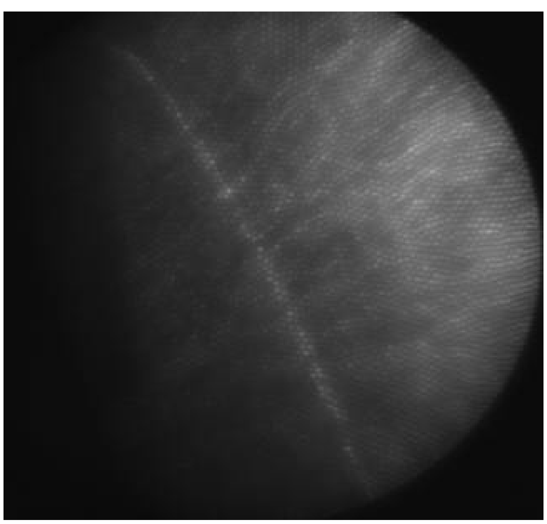
Flexibility becomes a principal challenge when attempting these kind of AVI applications. In this case a 6 dof robot has been adopted. High level off-line programming is achieved by means of RobCad. CAD data from pieces is used for the necessary accurately trajectory planning.

5 Image acquisition strategy.

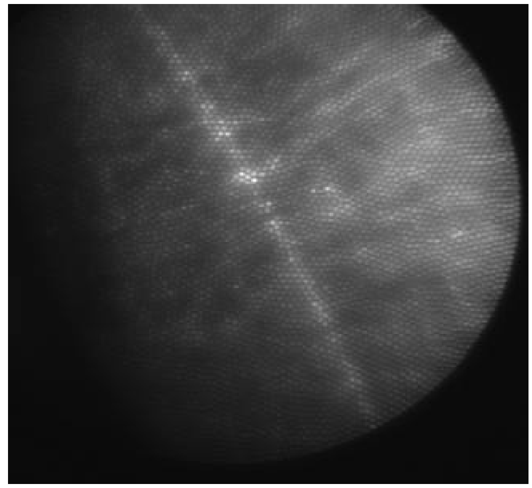
Image acquisition, a key point in every AVI system, sets up a critical point within SMARTMEC development, basically for the complex geometry of parts and for the high reflectivity showed by the machined material. For enhancing of the visual properties of the machined surface, technology present at every workshop is MAGNAFLUX™ , that is, the use of UV light and magnetic solution. This technique consist, basically, on flushing the piece under inspection with a water solution containing metallic particles. These particles, under the effect of a strong magnetic field, get aligned following the shape of surface defects like pores or scratches, which results in defect enhancing.

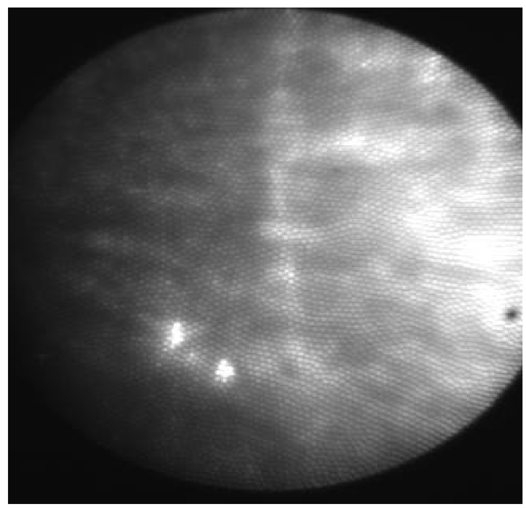
MAGNAFLUX™ has been avoided by an smart optical image acquisition device using coherent optical fibres. It assures a constant incident angle of light over the piece's surface and constant camera-to-surface orientation.

Illustrations 2 to 4 show critical defects -fissures, pores, cracks- as seen by the CCD camera.



Illustr. 2. 0.09 mm fissure.





Illustr. 3. 0.1 mm crack.

Illustr. 4. 0.3 mm pores.

6 Defect segmentation.

For defect segmentation purpose, algorithms based on a mixture of techniques as local thresholds, regions' connectivity, Hough transform and texture analysis [8] have been developed. First, raw image is filtered by and original meidan-based algorithm which decides if actual pixel beleongs or not to defect depending on its difference with the median value. Second, segmentation is attempted by a combination of threshold and area-based filters which results in potential "defective" portions of the piece. Fianlly, Hough transform is used to decide about previous segmented portions, depending on portions' orientation.

7 Image recognition module

Considering that every defect is composed by a set of different segmented objects, once the real-time image processing module extracts those features corresponding to all objects from a defective zone of the mechanical piece -low level data-, these features are sent to the Data Base. Afterwards an AI-based system attempts to classify them into categories corresponding to different types of defects.

Classification is based upon two data sets: in one hand information about defect visual appearance -as seen by cameras once they have been enhanced- and in the other hand low level data from feature extraction. Low level data is structured in messages coming from the image processing hardware as follows:

Board_id
Camera_id
number_of_objects(not NULL)

01 object
area
orientation
enclosing rectangle (x_1, y_1, x_2, y_2)
gravity_center (x_g, y_g)
gray_level (clear/dark)
north_connection (x_pos, n^{er} pixels)
south_connection (x_pos, n^{er} pixels)
west_connection (y_pos, n^{er} pixels)
east_connection (y_pos, n^{er} pixels)
…
object

Structural approach can be applied, since heuristic knowledge about defects is available. In this approach searching trees are the basis for classification, since they represent the basic patterns for grammars associated to each defect type. Two separate classification approaches can apply: rule-based methods and theoretical decision methods.

First approach is based upon syntactic methods. Its basic principles consist of basic structural patterns' definition jointly with determination of rules that govern their interconnection. Up to now we have envisioned the following basic structural patterns:

- Clear Longitudinal Band (CLB)
- Clear Transversal Band (CTB)
- Clear Point (CP)
- Dark Point (DP)
- Clear Speckle (CS)

Under this approach a medium level qualitative information (structural patterns) is derived from low level data -extracted features from objects- which should constitute primitives or terminal elements of the grammar associated to each defect type. The set of rules that applies over this grammar should permit to know if resultant sentence belongs to some defect type, when applied over terminal elements.

Second approach, theoretical decision, is also applied; in this case, a typical pattern recognition scheme would is used. Features from known patterns are used to train the PR system in a way that the feature's space is divided into n different regions (considering that n defect types exist); any new feature vector coming into the PR system are selected as belonging to any of the defined classes.

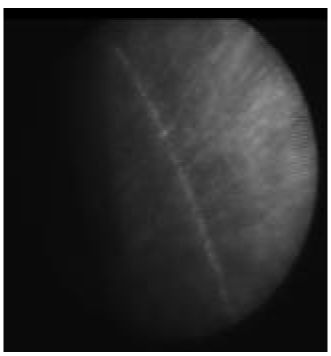
This configure an hybrid PR system, where syntactic methods are used in combination with Neural Networks. In this scheme, all classifiers perform over the feature vector. At the top a supervisor selects which is the classifier with greater success probability, based on earlier experience about correct classification.

8 Results.

AVI System within SMARTMEC is being developed by D*ept. FAIS* of the *Universidad Politécnica de Madrid* for RENAULT VI in Spain and IVECO FIAT in Italy. At present a test bed is being arranged for testing purposes.

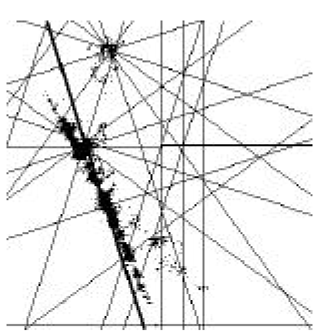
Illustrations 6, 7 and 8 show a complete process from image acquisition to defect detection.

The designed interface includes a menu driven adjustment of inspection parameters like feature selection, thresholds, piece's kind,..., with visual feedback. Other parameters like integration time for cameras, light selection, ... are automatically performed by the system. This feedback allows the inspection supervisor to have on-line information when updating inspection parameters, which has made possible to on-line change the inspection strategy.



Illustr. 6. Filtered image of illustr. 2.

Illustr. 7. Segmented defect.



Illustr. 8. Defect's direction.

Actual prototype's performance qualities include the inspection of up to ten complex pieces, e.g. crankshafts, by hour. This imply a reduction of cycle time by 90% -this includes avoidance of MAGNAFLUX process-, which makes feasible the on-line inspection of every produced parts.

Acknowledgements

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