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APPLICATION OF THREE-DIMENSIONAL SEGMENTATION TECHNIQUES FOR PRODUCT DEFECTS INSPECTION

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ABSTRACT
During the post-manufacturing life-cycle(assembling, packaging,…) the object surface could interact with other surfaces modifying its morphology with the introduction of local damages (scratches, bumps,…). Following quality principles and especially working with aesthetic components it is very important to detect these defects on the objects surface in order to fix it and to grant to the costumer a acceptable product. While for elementary geometries the inspection procedure are already standardized, working with sculptured ones (FREE-FORM), typical of the aesthetic components, the shape inspection strategies are not so known. In fact normally working on single components the inspection phase can be implemented manually by an expert operator that develop a complete visual inspection of the surface. But moving the attention on automated production lines this manual approach has to be substituted by an automatic one. So starting from the experience developed with reverse engineering and 3D scanner systems this work wants to propose an automated inspection strategy based on a segmentation reverse engineering strategy.
Keywords: Reverse Engineering, Scanner 3D, Surface Metrology

1. INTRODUCTION
The morphology of an engineered surface is the result of material removal, plastic deformation, and material accumulation phenomena taking place at different scales and in different time frames, due to the interactions with other surfaces and with the environment during the surface manufacturing and post-manufacturing life-cycle. As a consequence of this, the object surface is normally characterized by typical manufacturing features, as well as bumps, scratches and other defect typologies. The importance of the defects increases especially working with automotive components, casings for household items, consumer electronic goods or in general industrial design products with important aesthetic functions.
As a consequence of this every manufacturing company, in order to grant a certain level of efficiency, has to develop efficient and reliable inspection methodologies in order to control eventually production problems and to grant costumers the highest quality.
But conventional inspection procedures often are not easy to be implemented and so they aren’t the right solution to grant the need quality level. Working in fact with aesthetic components the morphology of the objects has normally to show a smooth behavior and for this reason its description normally is obtained with the use of free-form surfaces.

This kind of geometries are normally complex and it is not so simple to develop repeatable inspection strategies, for the absence of frames, given normally by elementary geometries, and conventional geometrical tolerances.
But in the last years, surface acquisition techniques in the mechanical sector have shown considerable progresses and actually some of the available 3D scanners are able to provide fine scanning accuracy and very fast scanning capabilities, very interesting for Free-form surfaces inspection[1,2].

2. DEFECTS IDENTIFICATION STRATEGY

Working on aesthetic products normally the quality control phase should normally to detect bumps, scratches and other kinds of local damages (Fig.1).

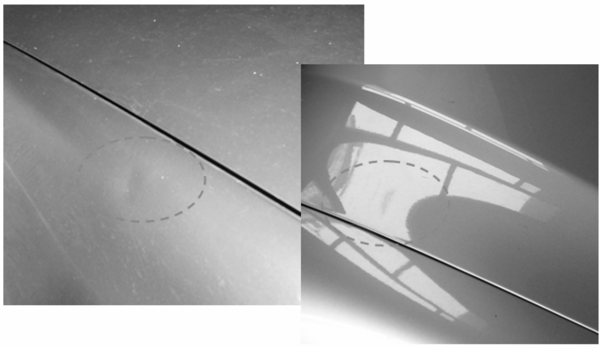

Figure 1.Free-Form surface aesthetic object defects examples

Working on a single object the most reliable method to identify these anomalies is surely the visual inspection of the object surface. Thanks to his experience the operator, normally developing a sort of unconscious differentiation process, individuates the main features that characterize the object surface and then identifies which are due to the manufacturing process and which to uncontrolled interaction of the object with other surfaces (scratches,…) .
Considering the necessity to increase the performances of this manual inspection method and to move the unconscious differentiation method to a conscious automated one, the idea is to formalize an automatic methodology that in a first phase partitions the object surface acquired into regions, according to the similarity of local surface attributes and working with a **morphological descriptor M_i**, and in a second phase classify the identified regions in different families characterized by specific **topographical descriptor Tj** (sample height, local derivative, local maximum sharing), defining if the identified region is a manufacturing [3] (Fig.2).

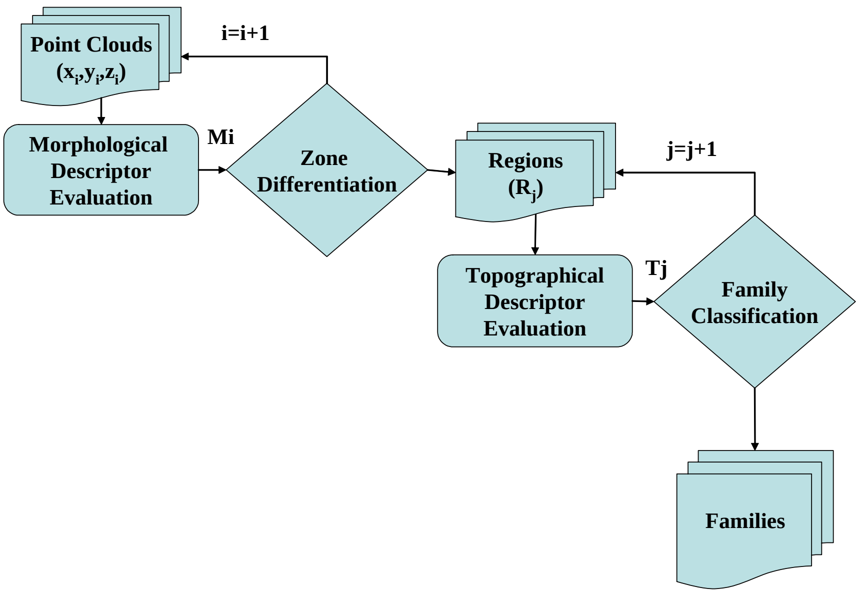

Figure 2.Inspection methodology flowchart

The paper has mainly focused its attention on the first differentiation phase employing for this stage a reverse engineering segmentation approach. Following a region growing method [4,5] the proposed segmentation algorithm wants to partition the object surface working on the Gaussian curvature and employing, as segmentation threshold, the 3D scanner measurement uncertainty[6]. At the end of this stage the proposed method proposes a complete description of the object surface (morphological map) detecting the boundary of the regions that show similar curvature values.

3. SEGMENTATION PROCEDURE AND MORPHOLOGICAL DESCRIPTOR

The segmentation procedure proposed starts with the choice of the local morphological descriptor. Starting from previous experiences it has been decided to use the Gaussian curvature as morphological descriptor because evaluating its local variation over the entire object surface it is possible to implement an efficient shape-changes detection strategy. This choice is justified considering that the presence of local damages on a free-form surface is normally characterized by sudden shape-changes. The curvature K has been evaluated working on discrete zones characterized by six triangles converging on a central node:

$$K = 2\pi - \sum_{i=1}^{6} \arccos\left\{ \frac{(x_i - x_0)(x_{i+1} - x_0) + (y_i - y_0)(y_{i+1} - y_0) + (z_i - z_0)(z_{i+1} - z_0)}{\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2}\sqrt{(x_{i+1} - x_0)^2 + (y_{i+1} - y_0)^2 + (z_{i+1} - z_0)^2}} \right\}$$

Once the Gaussian curvature has been evaluated on the entire point clouds, the algorithm evaluates the Gaussian curvature variation comparing all the six K curvature values of the surrounding points. At this stage in order to define which zones presents a significant shape-change it is necessary to define a realistic curvature variation threshold. Considering that the points cloud has been obtained employing a 3D scanner it is necessary to neglect all the shape-changes that are under the measurement uncertainty of the scanner. For this reason employing the extended uncertainty concept [7] for the threshold definition, it is possible to introduce the measurement instrument uncertainty in the shape-change detection strategy.

$$U(K) = t \cdot \sqrt{\{\mathbf{C}\}^T_{1X\,21} \left[u^2(\xi)\right]_{21X\,21} \{\mathbf{C}\}_{21X\,1}}$$

where C represents a matrix containing the sensitivity coefficients of the main function.

4. EXPERIMENTAL VALIDATION

In order to have a concrete validation of the method it has been implemented working on a car spoiler that presents on its surface some scratches. The object has been acquired with the use of a commercial laser scanner (Fig.3).

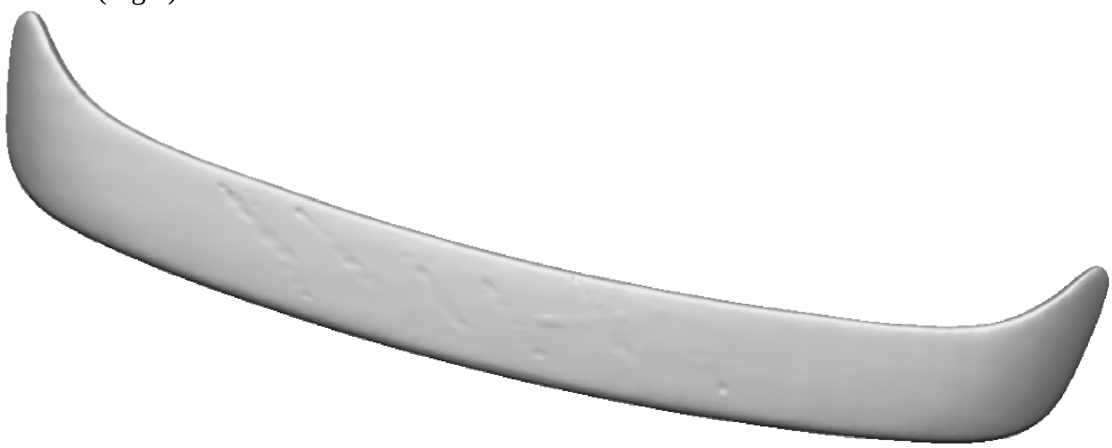

Figure 3.Car spoiler point acquired

As result the algorithm has underlined not only the scratches boundaries but also the spoiler ones because they show significant shape changes (Fig.4).

Figure 4. Boundaries detection procedure: the darker points represents those points selected by the algorithm as significant shape-changes boundaries

So in order to complete the differentiation process and to classify the regions that represent the scratches in the local damages family and the other underlined boundaries in the conventional features it is necessary to identify an appropriate topographical descriptor. For this specific experimental application the *sample mean height* has been employed considering that the scratches depth is normally smaller than the other geometrical features that characterise the object shape.

5. CONCLUSIONS

Integrating appropriate topographic parameters with a reliable segmentation procedure it is possible to adapt a general purpose partition procedure to different inspection methodologies. The use of topographic concepts and reverse engineering segmentation ideas in the defect identification strategies could improve the performance of the conventional inspection procedures developed on complex surfaces.

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