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Datum Identification for Tolerances Control on Dense Clouds of Points

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ABSTRACT

Optical Reverse Engineering systems are evermore used to check dimensional and shape conformity of manufactured components; their main advantage is the short acquisition time. Dedicated CAD software tools allow comparing the acquired data (clouds of points) with the 3D CAD model. Generally, they support the automatic global shape measurement; from the designer viewpoint this is not sufficient. The desired functional behavior of component is respected only when specific geometrical tolerances are verified. Our aim is the definition of methods to automate this last control process using *Full of Information (FoI)* CAD models. We define them as 3D model containing tolerance attributes and methods to check them. They allow comparing the toleranced features with the corresponding parts of point clouds. The present paper describes the approach and the developed method for datum identification usable for orientation and localization geometrical tolerances control.

Keywords: reverse engineering, geometrical tolerances, quality control.
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1. INTRODUCTION

Manufacturing processes are intrinsically imprecise, producing parts that vary in size and form. The need to control the quality of production and to manufacture parts interchangeably led to the development of tolerance specifications. They have been subdivided in dimensional tolerances and Geometrical Tolerances (GT). These are prescribed to verify if desired product functional features, defined during the design phase and represented by toleranced geometries, have been respected after the manufacturing process. Tolerance specifications are the critical link between the designer and the manufacturer. Designers prefer tight tolerances to ensure that the part will fit in the assembly and perform function. Manufacturers, on the other hand, prefer loose tolerances to lower the production cost and decrease the need for quality machine tools and precision measurement machines. The cost of inspection process is strictly related to the number of pieces to be verified and the typology of tolerances. Generally, these control processes are time consuming, and they require high-skilled operators able to apply the GT inspection rules using Coordinates Measurement Machines (CMMs). To saving time the measurements are realized on a small-sized sample drawn from a lot. This inspection modality generalizes the quality characteristics of the sample to the lot from which the sample was drawn. This approach reduces the control time but the percentage of errors can be relatively high. Hence, the reduction of complexity, time and cost addresses the research towards a complete automation of the control process. The automation can be achieved in terms of measurements planning through Computer Aided Tolerancing and Inspection software packages, based on 3D CAD models data, which can pilot the measurement system. On the other hand the acquired data have to be automatically elaborated by a comparison with the specifications of the designed 3D model.

In this context, the goal of our research is the study of easy-to-use solutions to facilitate the applicability of GT. We assume that the main rule is to strongly link the design and the inspection phases. This assumption agrees both with the present principles of the ISO standards and the simultaneous engineering approach where the designer has to manage and prevent problems also of the tolerance control process.

The studied method [1] aims to develop a Computer Aided Tolerancing and Inspection tool based on the integration of feature-based CAD models and 3D optical digitizing systems. In more details, the product model structure has been defined and extended to implicitly collect, within the model data structure, the designer tolerance specifications as geometry attributes. The product model has been represented by a Full of Information (FoI) CAD model and a knowledge base which verifies the coherence of tolerances prescriptions. Such a model becomes the reference to compare automatically the measured data. In fact, a fast optical 3D shape acquisition system can provide an accurate virtual representation (point clouds) of the manufactured object. Point clouds analysis algorithms have been developed to separate the different zones corresponding to the basic CAD modeling surfaces. A matching method enables to map them with the FoI CAD model features attributes. Finally, specific algorithms have been studied and implemented to apply GT verification rules on these virtual models. In this way it is possible to support a reliable and automatic inspection process based on the ISO and/or ANSI/ASME standards procedures. Furthermore, the designer specifications can pilot directly the product verification stage involving a minimization of errors due to operators' misinterpretations.

In this context, the present his paper describes a developed method used to identify robust datum geometries on the point cloud, in particular axis and planes, useful for orientation and localization tolerances virtual control. This method is one of the possible approaches considered in the GT verification software tool.

The remainder of the paper is organized as follows. In Section 2 we review as reverse engineering methods are used in GT verification. Section 3 describes the proposed approach for automating such control based on the FoI CAD model. The next section is dedicated to illustrate the method for identifying datum and toleranced geometries on the point clouds in conformity to the international and national standards (ISO, ASME, VDI, …). Section 4 and 5 describe also the preliminary experimental results. Last section concludes with a summary and a description of future work.

2. RELATED RESEARCH BACKGROUND

In these last years the ISO/TC 213 (Dimensional and Geometrical Product Specifications and Verification) is carrying out a meaningful rethinking work of procedures and standards related to the tolerancing problem. In particular, they have uncovered a set of rules showing the correspondence between processes of tolerance specification and tolerance verification. This allowed theorizing a harmonizing of set of operations involved in such two activities. The resulting principle has been defined as "duality principle" [2]. In fact, two main operators have been determined: the specification operator and the verification operator. Each operator contains a set of feature operations that are dual between the groups; such one-to-one mapping provides an integrated view of the tolerancing problem.

An open issue is the development of methodologies and tools, which allow the efficient application of such principles and operations. They cannot disregard the tolerances representation within the design systems, in particular within the three-dimensional CAD software packages that are used during the design intent definition. Many tolerance representation models have been studied and proposed. They have been finalized to support different product development phases. As reported in literature [3], they can be classified in: documentation oriented, analysis oriented, production oriented and control oriented. From the CAD modeling viewpoint, the use of feature-based approach has been largely investigated. For example an interesting method to link dimensioning and tolerancing schemes in CAD systems, based on graph representation, has been described in [4]. A feature classification (atomic, primitive and compound) has been defined as base to implement a tolerancing module in [5].

In our approach the feature-based CAD model with tolerances is documentation oriented, since it collects the nominal geometry and the related tolerances. The analysis of data structure allows the identification of the atomic and compound features with tolerances; the resulting sub-model is "augmented" with relations between features and verification procedures. This information can be used to determine the skin model, as defined in [6], and to perform the comparison between the real model and the skin model itself.

The other part of the dual model is the virtual representation of the real object, as a set of point cloud data, once it has been digitized. Several technologies allow the acquisition of the 3D object geometry, but the optical systems, especially based on the triangulation principle, have evident advantages in terms of speed and usability. Their adoption for inspection tasks has been widely studied [7], [8]. The measurement accuracy is not comparable with CMMs but such systems are in continual improvement [9].

The connection between CAD models and 3D inspection systems has been approached to determine optimal inspection strategies [10], driving the scanning system for freeform surfaces and related data verification. The point cloud data analysis to perform the geometrical tolerance verification is a consolidated functionality of more common reverse engineering commercial software systems (RapidForm by Inus Tech., Geomagic Qualify by Raindrop, Polyworks by Innovmetric), but they provide only algorithms to facilitate the feature extraction within a dense points cloud. In fact, they are completely disjointed from the tolerance specification process and, furthermore, they require constant user interactive decisions for verification task and data segmentation. An advanced and integrated solution proposed in literature [11] is the most effective example of verification automation, but the CAD model is used only as reference to perform the range data segmentation activity. A robust method to partition the point cloud data [12] is one of the main problems to be considered.

3. GEOMETRICAL TOLERANCE VERIFICATION APPROACH

The proposed approach is based on optical 3D digitizing systems that generates a dense point cloud data; such data are spatially sub-sampled and filtered to eliminate spikes. The point cloud noise is neglected for two reasons: the more advanced 3D digitizing systems generate good quality data, the values of checked toleranced under investigation is larger than 0,1 mm. The resulting extracted data are partitioned using a methodology based on local differential properties [13] calculated directly on point cloud data. These sub-clouds are used to identify the skin model and to represent the real object geometry to be verified.

A simplified block diagram of the inspection process is shown in figure 1. The boxes in the figure indicate the order of processing and illustrate the use of information generated.

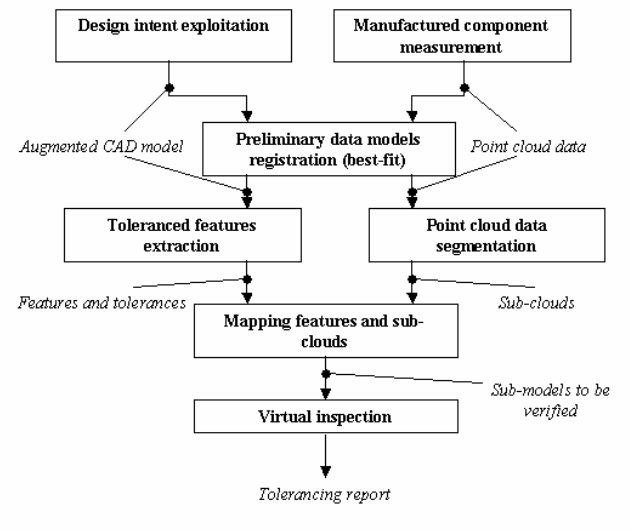

Fig. 1: Block diagram of the inspection process proposed.

The designer, during the product modeling phase, exploits the design intent through the conditions to fulfill the required functions. They are expressed in terms of shape, dimensions, movements, etc.. Once the 3D model is realized he/she can prescribe and link tolerancing attributes (datum, tolerancing values and tolerancing typologies) to the atomic (such as points, axis, lines) and compound features (such as surfaces, groups of lines, groups of faces, …) on the basis of required product functionalities.

These attributes are stored into CAD data structure, consisting in a part of the FoI CAD model. This model can be automatically navigated to extract the explicit information for the tolerance verification. In particular the features extraction operation finds elements interested in tolerance prescription generating an ordered list of properties for each feature as follows:

Tolerance (id. number), method (group, typology)

Feature (id. number), Typology (i.e. axis), CofG (Gx, Gy, Gz), Datum (id. letter), Tolerance (typology, value, datum).

The first row indicates a number that represents a specific tolerance prescription, highlighted in the following rows; such progressive number univocally identifies each tolerance attached to the CAD model. Furthermore the method to be used for the specific tolerance verification is reported; these methods are collected into a knowledge base that provides rules and procedures. For example if an orientation tolerance is prescribed, the first task is the datum identification and the determination of its configuration (since it could be a combination of features), then the toleranced geometry must be found and finally, on the basis of tolerance typology (parallelism, perpendicularity, etc.).

In the following rows is identified the specific information related to datum and toleranced geometries.

The CAD model data structure is analyzed and when a tolerance specification is located the software system looks for all the related specifications (generally the datum) and defines/updates a list that is ordered according with the tolerance identification number and summarizes all the tolerance specifications assigned with the logical scheme previously described. The further interesting aspects are linked to the last two tasks of figure 1 (mapping and inspection). The mapping between toleranced features and the corresponding point sub-clouds data is carried out using algorithms to calculate minimum distances. The information of centers of gravity (CofG) coordinates, that is the point itself in the case of a point datum, or the middle point in the case of an axis datum, is compared with the set of the sub-clouds resulting from the segmentation. The cloud at minimum distance is identified as the right sub-cloud.

Once the other tasks have been successfully performed, the virtual inspection process can take place.

The appropriated inspection method is selected according to the specific GT category and type to be inspected. First, the method must describe the procedure to precisely identify the datum geometry on the sub-cloud. For each different datum and tolerance type different strategies can be identified. Once the virtual datum has been identified, the method describes the procedure for the computation of the tolerance zone. Such procedure allows carrying out the verification process simulating the operations similar to the traditional verification methodologies. Finally, the points belonging to the sub-cloud corresponding to the geometry to be inspected are checked in order to verify if the tolerance zone bound them. In the following section a method for datum feature identification, as part of "virtual inspection" activity, is reported.

4. RELIABLE DATUM IDENTIFICATION METHOD ON DENSE POINT CLOUD

4.1 Classification of Toleranced Geometries and Standards Prescriptions

From ASME standards prescriptions [14] we can subdivide geometrical tolerances in 5 different categories: form, profile, orientation, location and runout.

Among them, we are focused on orientation and location tolerances that seem to be the most used specification.

Form tolerances are: flatness, straightness, circularity and cylindricity. These entities are individually defined; it means that they do not require reference geometry (datum) to be verified.

Orientation tolerances concern the angular positioning of surfaces or axis in the respect of a datum plane. They are subdivided in perpendicularity, parallelism and angularity. Perpendicularity is the condition imposed when a surface, or center plane or axis, is at right angle to a datum plane or axis. Perpendicularity tolerance specifies a zone that lies between two parallel planes that are perpendicular to its reference plane (datum). In case of cylindrical axis verification it consists with a cylindrical zone perpendicular to the datum in which the cylinder axis must lie. Parallelism is the condition of a surface, axis or center plane that prescribes equidistance of its points from a datum plane or axis. Parallelism tolerance specifies a zone that lies between two parallel planes that are parallel to its reference plane (datum). In case of cylindrical axis verification it consists with a cylindrical zone perpendicular to the datum in which the cylinder axis must lie. Angularity is the condition of a surface, axis or center plane at a specified angle other than 90°. Perpendicularity, parallelism and angularity tolerances specify a zone that lies between two parallel planes constrained to be respectively perpendicular, parallel or at a specified angle to the appropriate datum.

Location tolerances prescribe position conditions or concentricity and symmetry. They are generally used to control center distance between such features as holes, slots or tabs; location of groups of features; coaxiality of features and concentricity or symmetry.

Positional tolerances define a zone within which the position of a center or an axis is has to be localized or a boundary virtual condition that cannot be violated by the surface of the considered feature (concentricity or symmetry tolerance). To define such tolerances datum features are always mandatory, together with the application of so-called modifiers (MMC, LMC, …) just to evaluate the range where the actual condition may be verified. In the next paragraph these tolerances are mainly discussed from the datum identification point of view, presenting a procedure to identify datum such as planes and axis, starting from the point cloud achieved by digitized shape acquisitions.

4.2 Point Cloud Processing for Datum and Tolerances Identification

Reverse Engineering (RE) techniques are able to sample the real object with a large number of data, usually 10^3-10^5 time greater than a standard procedure. Without regarding measurement system accuracy, the acquisition of a large sample set may improve the quality of the feature reconstruction but, on the contrary, the problem of the True Geometry Counterpart (TGC) recognition arises. In the real practice the measurements are usually made positioning the part on a reference frame. It represents an envelop of the so called TGC. Using RE technique two different cases can be faced. One assumes to measure the component positioned on a reference frame that represent the datum features of the part; the other acquires the whole component free in the space (e.g. merging multiple scan views). In the first case the point cloud can be easily changed into the CAD reference system, by a rigid motion, and the features to be verified can be easily compared with the imposed tolerances according with the datum (that is equivalent to the measurement reference frame). So in this case, the main problem is to associate an ideal feature to the discrete real one. In the second case, before reconstructing the ideal shape from the acquired cloud, it is necessary to fit the datum references.

In this work the second case is addressed. In particular it presents an integrated approach for evaluating associated ideal geometry fitting and, datum evaluation.

Segmented point clouds represent the discrete model of the real part. From such points features must be fitted. In case of tolerance analysis, whatever the measurement device is, it has been proved that the least squares error approach may overestimate the error [15]. This may lead to reject good components. To overcome such limit different approaches have been studied to define the minimum tolerance zone. Among them the Convex Hull approach seems to be one of the most promising [16].

The convex hull is the smallest convex set that contains all data points. The method iteratively checks each pair of anti-nodal data points looking for the minimum distance between parallel lines that pass through the anti-nodal points, encompassing all the data set. Computational efforts of such approach are huge so that different linearization procedures have been proposed [17]. Another computational problem is the necessity of orienting the reference system in proper directions to simplify the equations. These disadvantages make the method less attractive for RE elaboration, that manage a cloud points of more 10^3 data than standard CMM acquisitions, where usually such approach is adopted. For this reason a different approach has been defined. It is still based on the same assumption of the minimum zone method, but it works differently. Here the first implementation is proposed together with basic comparisons with the least square errors method.

The actual practice of measurement requires fixing the component on datum features. With this procedure the most outer points of the real shape of the surface are put in contact while the most inner result quite far. In case of planes at least three outer points are necessary to fix one face of the part, but usually more than three are admissible. They define an envelope surface that must guarantee a stable position (no fluctuation across the contact surface). When more than a datum is required there are less degree of freedoms to be assigned during the second or the third contact due to fact that some constraints must be respected among these datum (figure 2, case A). Such constrains make change the contact points of the features if the order of positioning on the datum is changed (figure 2, case B).

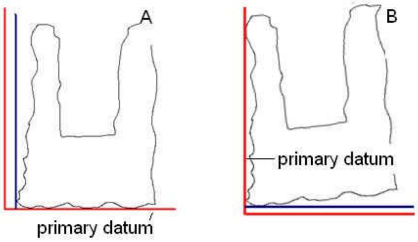

Fig. 2: True Geometric Counterpart definition. Case A: first datum is horizontal plane. Case B: first datum is vertical plane

Similar approach may be follow to find axis of cylindrical surfaces, when they represent datum features: their localization derives by locating the cylindrical surface into a similar TGC, that will pass through the most inner set of points (in case of holes and pockets) or the most outer (in the opposite case). So the cylindrical envelope surface, basis of the axis definition, must pass through this smaller set of points. Obviously if the axis is not a primary datum, the definition set must be constrained, thus reduced, to respect the primary condition (e.g. if in case B of figure 2 an hole exists and its axis is perpendicular to the primary datum the axis orientation is already fixed, while its application point must be found by the cylindrical surface).

The assumption of normal distribution of peaks and valleys of each acquired surface may allow to assume that the most outer/inner points of a surface, or cortical points, are randomly distributed along the feature thus the envelope surface that simulates the datum should pass through them. Starting from this assumption the proposed method works as follows. The extracted feature (plane, cylinder, …) is re-build by a least square fitting, then the set of point is ordered from the most outer to the most inner according to a distance analysis performed between the feature data set and the first guess surface. A proper percentage of the most outer points, named the cortical data set, is selected as the envelope set and is used to fit the envelop surface. The amount of outer points to be included in the computation is then the core of the method. Including all the data set will produce an envelop surface equals to the first guess surface obtained by a least square fitting. The new datum surface, in the case of planar features, will be translated respect to least square fitting surface and it will be oriented in a different direction.

Two approaches are possible to face the identification of new datum surface: to find it empirically or by an optimization procedure that will take into account the constraints of no surface intersection. The case studies proposed in paragraph 4.3 will discuss the empirical approach in comparison with the standard least squared method approach.

4.3 Test for Datum Identification (Plane and Axis) and Flatness Tolerance Control

To evaluate feasibility of the proposed procedure a preliminary test case has been set up to understand the limit of the methodology. It was artificially built starting from the CAD model defined in figure 3. It prescribes some of the most frequent geometric tolerances required in the common practice: flatness, orientation and location of holes.

From the outer surface of the solid model (ideal features), an ideal skin model was derived and sampled as a point cloud with a density similar to one achieved by an optical device. This discrete skin model was partitioned and the resulted features have been randomly perturbed according to the formula:

$$\Delta = t * rand([-0.5, 0.5]) \qquad (1)$$

Where t represents the specific tolerance associated to each feature.

Then each feature has been analyzed by the proposed procedure to assess if the method confirms the acceptability of the artificially perturbed geometry.

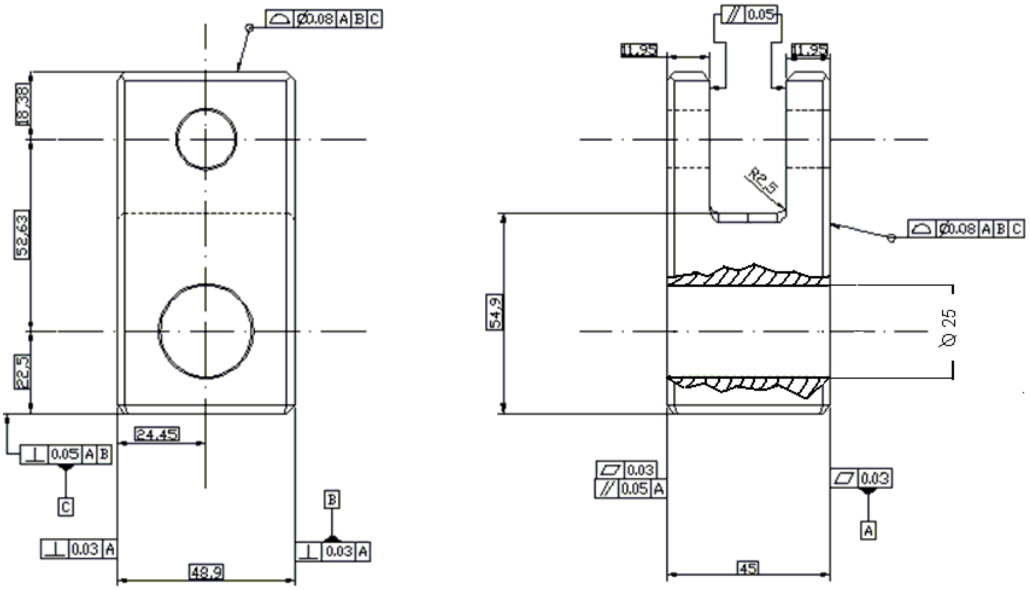

Fig. 3: Test case.

Figure 4 shows the component in different states of its elaboration: figure 4.A as solid model, figure 4.B as ideal skin model, figure 4.C as perfect discrete model and figure 4.D as discrete perturbed and partitioned point cloud.

The first step of the verification procedure consists of evaluating the planes associated to the datum.

The proposed method based on the cortical data set, let us call it Outer Point Fitting approach (OPF approach) is here compared with the datum evaluation made by a best fitting based on the Least Square Method (LSM approach). The main question about the OPF approach is related to the definition of a criterion for the cortical set definition.

Here it was decided to define it including all the points in the range of $[d_{max}, d_{max} -0.5\ t]$, where d_{max} represents the outer distance from the mean average plane achieved by the LSM approach.
After defining the cortical set, its fitting plane is computed. It represents the true geometric counterpart of the datum. It is evident that the identified datums are different using LSM and OPF; in the next section it is described a real test case where the difference is highlighted.
Furthermore, for each datum (A, B and C) two kind of information have been extracted and compared with the LSM approach: the flatness tolerance verification of each plane, and the fitting error estimators.

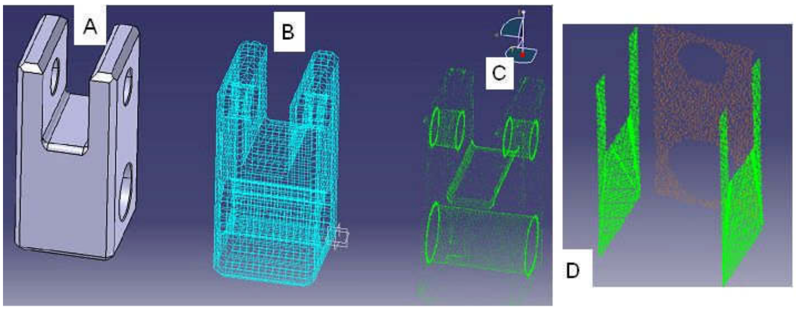

Fig. 4: 3D CAD model elaboration for achieving the reference planes.

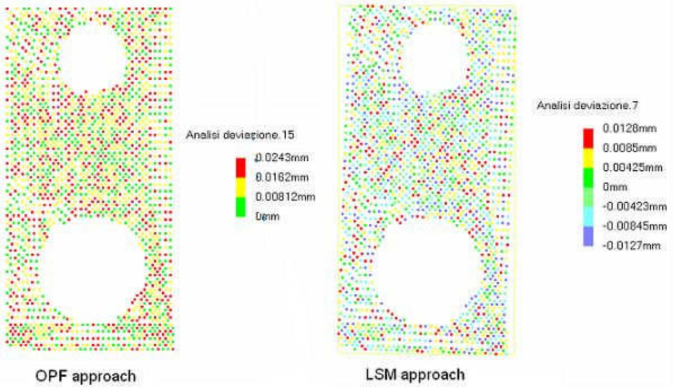

Fig. 5: Flatness verification of datum A.

Figure 5 shows flatness verification of datum A in the respect of the LSM approach (on the left) and the OPF (on the right). In both case it is verified by means of a distance analysis. In case of LSM approach the nominal value is set to be zero due to the fact that the fitting plane should represent a mid-plane of the whole data set. In the other case the scale is shifted to the cortical set so the average points of the whole data set should be at a distance of t/2 from the outer points. LSM approach always overestimates external point distances of about $0.3\ *10^{-3}$ mm, giving as result unacceptable flatness.
The inadequate approximation of the LSM method is confirmed comparing the error estimators of the fitting results, shown in Table 1. OPF approach always presents error and deviation less than 10^{-3} mm.
Table 1 shows also the percentage of points included in the cortical sets, together with the selection range. Although the percentage is less then 6% of the whole subset the de-localization of such points is confirmed by the Projected Area Overlapping (PAO), also reported in table 1, and defined as the ratio between the projected area of the cortical set and the feature area. A sensitivity analysis of the OPF approach has been performed increasing the percentage of points in the selection range. Due to the fact that the ideal surface is rebuilt by a fitting method the mean error of the evaluation is proportional to the number of adopted points, as clearly shown in figure 6. The maximum error is reached including all the data set, when the OPF approach equals the LSM.

LSM approach	**Datum A**	**Datum B**	**Datum C**
Max error (mm)	0.0128	0.0129	0.0128
Mean error (mm)	0.0062	0.0063	0.0058
Standard Deviation (mm)	0.0036	0.0036	0.0036
OPF approach	**Datum A**	**Datum B**	**Datum C**
Max error (mm)	0.0007	0.0007	0.0008
Mean error (mm)	0.0003	0.0003	0.0003
Standard Deviation (mm)	0.0002	0.0002	0.0002
Point %	4.8%	5.7%	4.7%
Selection range (mm)	44.9875, 44.9888	48.9125, 48.9912	0.0125, 0,0112
PAO	98.2%	96.9%	92.9%

Tab. 1: Plane identification:-fitting estimators.

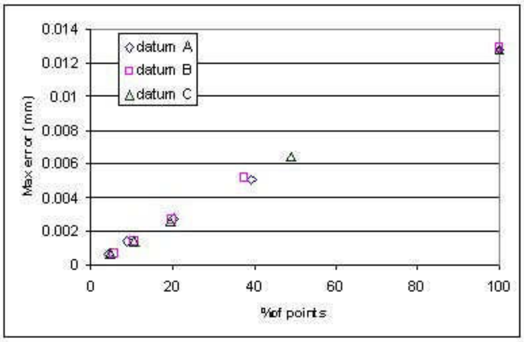

Fig. 6: Sensitivity analysis results.

From the previous test case it is possible to partition a cylindrical surface associated to the larger hole (R6.25 mm) for axis identification. Table 2 shows the results related to the application of both LSM and OPF approach.

The perturbation value adopted to simulate tolerance prescription was 0.06 mm. The most inner set of points has been defined taking all the points inside the range [R_{min}, R_{min} -0.5 t], where R_{min} represents the minimum distance between the cloud and the axis associated to the LSM reconstruction; this set includes about 7% of the total points.

	LSM approach	***OPF approach***
R (mm)	12.4994	12.4711
Max error (mm)	0.0398	0.0086
Mean error (mm)	0.0141	0.0023
Standard Deviation (mm)	0.0087	0.0017

Tab. 2: Axis identification: fitting estimators.

In figure 7 a cylindricity evaluation is given using both the methods. In the case of LSM (figure on the left) all the radial distances are in the range [-0.049 0.034] mm, while in the case of OPF they are always below zeros and in the range [-0.075 0] mm. Also in this case the adoption of the classical LSM overestimates the point distances of 0.013 mm.

5. EXPERIMENTAL RESULTS ON A INJECTION MOLDED COMPONENT

The experimental work has been conducted on an injection molded component: a carter (figure 8, upper), used for automotive application (courtesy of Volkswagen AG). In this component the plane along the carter profile has to be considered as datum for holes localization and it has to be planar: the tolerance prescription is 0,5 mm along a length of 100 mm, while the planarity of the whole feature is 1 mm (figure 8, lower).

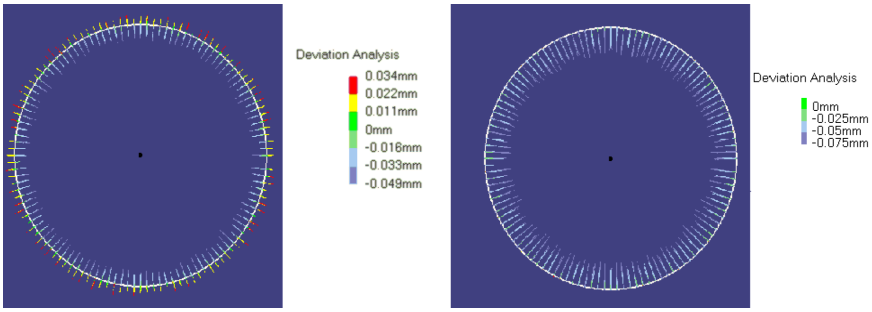

Fig. 7: Cylindricity evaluation (LSM on the left, OPF approach on the right).

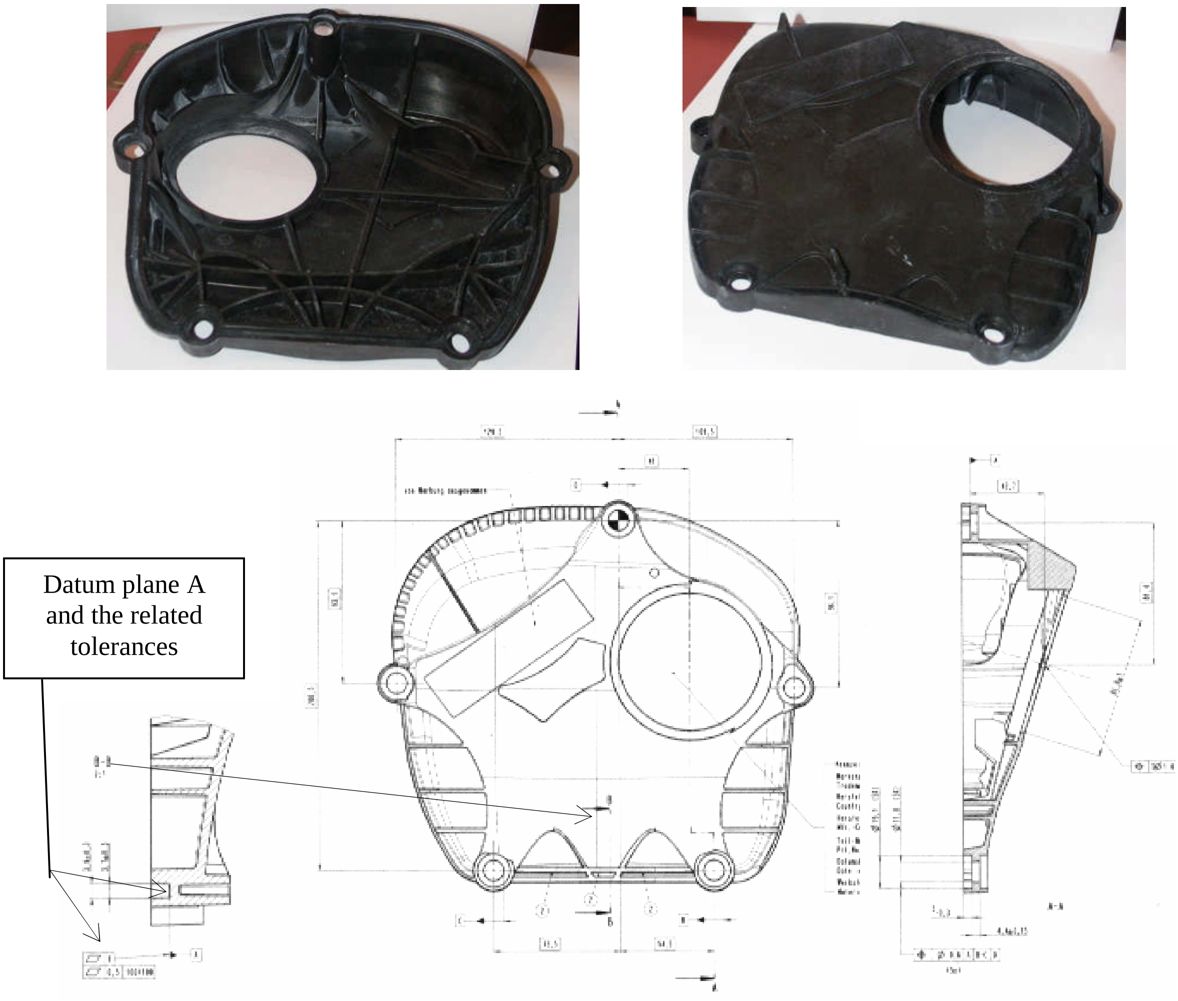

Fig. 8: Carter used as test case (upper) and datum feature as reported in the carter drawing (lower).

The carter has been acquired by COMET IV 250 (by Steinbichler Gmbh) that is able to measure a dark surface without loss of information and with irrelevant noise if compared with the required accuracy (order of tenth millimeters). One view has been sufficient to digitize a meaningful portion of plane (figure 9, left). The point cloud has been elaborated to extract the planar datum feature.

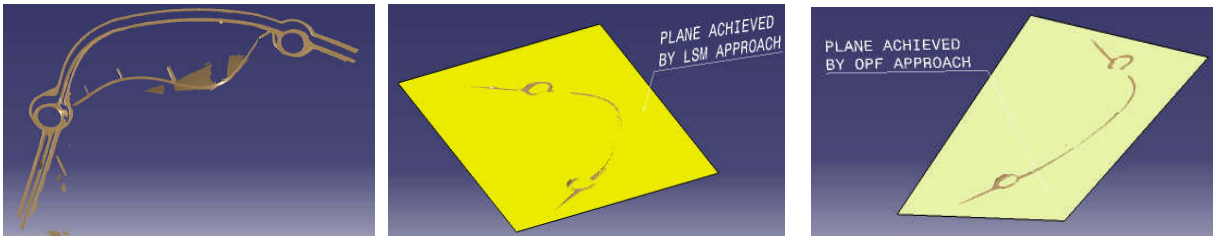

Fig. 9: The point of cloud acquired (left), the plane approximated by LSM approach (center) and the plane approximated by the OPF approach (right).

In figure 9 are reported the two different planes calculated by the LSM approach and the OPF approach; it can be noticed that in the second case the achieved plane is "positioned over" the point cloud. From a practical point of view, it can be considered a realistic behavior.
The distance analysis between the two planes is illustrated in figure 10. The maximum value is 0,212 mm, while the minimum value is 0,093 mm and the LSM plane is translated towards the cloud of points. We highlight that the datums are different.

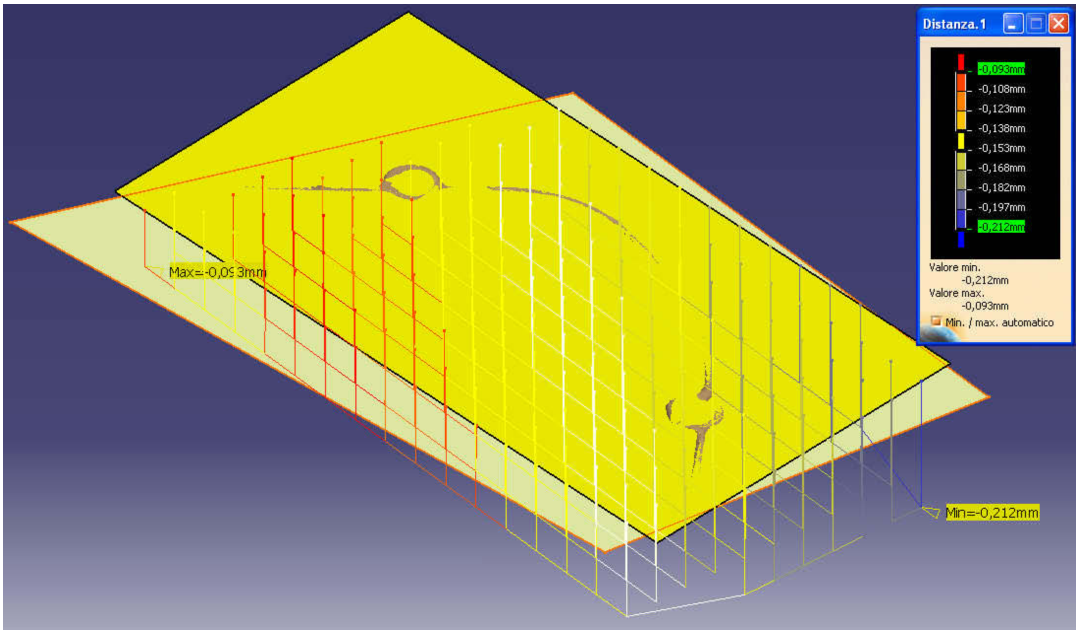

Fig. 10: The datum plane elaboration that highlight the difference between the proposed OPF and LSM approach.

A parallelism measurement between the datum plane and the upper plane of carter profile has been performed by CMM system adopting a physical set-up to generate the datum; hence it can be considered the real TGC. The virtual measurement has been also executed using the two different datum planes. The results show a better correspondence between the OFP approach if compared with the LSM approach; the difference in terms of parallelism value is around 0,15 mm.

6. CONCLUSIONS

In this paper it is presented an empirical method for datum geometry identification to be applied in tolerance control by means of RE techniques. Standard methods applied in case of CMM systems are very time consuming, thus inadequate to be applied in case of over 10^3 point cloud. Because the industry seems to require higher efficiency and automation for quality control, the adoption of optical devices and RE techniques seems an interesting approach whenever moderate accuracy is required. A reliable method for datum evaluation and TGC is the starting point for all the geometric tolerance verifications, according to standard prescriptions, for this reason an empirical method, based on the principle of the TGC detection, is here discussed and applied to find plane and axis datums. Their computation has been analyzed and compared to one of the most adopted approach in the RE field (by least square method), that in case of planarity and parallelism it was demonstrated to overestimate the minimum tolerance zone.

A first case study confirms this inadequacy of the last square method and does not reveal such weakness for the proposed approach. This encourages planning further works to extend the definition of such procedure to all the tolerance prescriptions and test its reliability on different real cases.

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