Title:
Automatic Post-processing for Tolerance Inspection of Digitized Parts Made by Injection Molding

Authors:
Michele Bici, michele.bici@uniroma1.it, Università di Roma La Sapienza, Italia
Francesca Campana, francesca.campana@uniroma1.it, Università di Roma La Sapienza, Italia
Alessio Trifirò, alessio.trifiro@it.abb.com, ABB SpA – Automation Products Division, Pomezia

Keywords:
Reverse Engineering, Computer Aided Tolerance Inspection, Segmentation, Hierarchical Space Partitioning, Plastic Injection Molding.

DOI: 10.14733/cadconfP.2015.313-317

Introduction:
Injection molding is one of the most widespread manufacturing systems for high volume production. In case of electromechanical components (dimensional range between 25-150 mm, shell thickness 0.5-0.8 mm), Reverse Engineering (RE) may play an important role to understand weakness of the product-process design. Arrangement of the cavities on the die may locally change injection and cooling parameters, producing sinks, weld lines, burrs or global shape defects (warpage). Residual stresses induced by shrinkage are major responsible of these defects and, of course, they affect dimensional and geometrical tolerances of the parts. For this reason, in electromechanical assemblies, inspection of functional tolerance represents a relevant aspect to validate die design, in particular if a large amount of parts is made as multiple cavities on a single die [2], [5]. Although the injection molding process has a tolerance compatible with laser scanner measurements (±0.05 mm versus an accuracy of 0.025 mm) or other enhanced solutions (e.g. grey code and phase shift systems), RE applications concerning the evaluation of dimensional and geometrical tolerances are not a well-established industrial tool yet. It is due to methodological problems associated to: (1) the post-processing of the cloud of points, (2) the assessment of the measurement protocol; (3) the hardware set-up according to the acquisition paths and conditions [9]. As a consequence of these problems suitable software able to aid the RE inspection through automatic analysis of components is still missing. In [6] an exhaustive state of the art concerning RE for tolerance inspection is presented together with a general frame for evaluating Geometrical Product Specification according to ISO standard. Nevertheless, the attention is mainly focused on how extract the tolerance value not on the post-processing automation. In [3] we analyze the inspection process usually made by a Co-ordinate Measurement Machine and that one based on RE techniques. RE techniques may support the automation of the inspection process mainly through a segmentation based on part type recognition. Doing so the component shape can be rebuilt and analyzed without asking for CAD alignment. It is of particular interest to avoid user interaction, when a large amount of inspections is required, as in the case of the injection mold set-up. The preliminary set-up of this automation has been discussed in [3] and applied to recognize planar surfaces of a din rail clip made by injection molding. In [4] the feasibility of recognizing also cylindrical surfaces has been presented together with the computation of a component reference system, named Intrinsic Reference System (IRS), usable to orient the cloud of points in the space without the necessity of CAD alignment. In this paper, we continue this endeavor discussing the enhancements made to enlarge the capability of the method, in particular: (1) the algorithms we adopted for finding and clustering cylindrical surfaces; (2) some improvements on the evaluation of the thresholds necessary to partition the surfaces and (3) the computation of the IRS.

Main idea:

Feature segmentation is not often an easy challenge, particularly if scanned parts have a high number of features. Ordinarily, in the RE of mechanical components gradient analysis is one of the most adopted solution [1], [10], especially in case of free-form shapes. It is generally applied on the tessellated surface or on a suitable reduction obtained replacing each triangle with its centroid. Therefore, it is clear that the accuracy of the analysis is extremely tied to the number of points, their density and distribution. Electromechanical components manufactured via injection molding are characterized by planar and cylindrical surfaces with sharp angles, low thicknesses and many small ribs. This reduces the complexity of the gradient analysis, since free-form surfaces are absent. On the contrary dense cloud of points are usually acquired due to the small size of many details and to the necessity of measuring also global shape distortion. As a consequence time-consuming post-processing is required. To reduce computational efforts, in [3] we derived from the concept of Hierarchical Space Partitioning, [8], a segmentation algorithm based on a voxel approximation of the component. A virtual 3D structure is superimposed to the point cloud, like a bounding box, and then, this structure is subdivided into elementary volumes (becoming the voxel structure) in which the presence of points makes a voxel treated as in a binary system. Its value is "1" (true state) if it includes points of the cloud, "0" (false state) if it does not. The creation of the structure starts from a single voxel and then, along each direction, it is recursively split into smaller voxels (every voxel is subdivided into 8 smaller voxels at each iteration) until no more points are included or an imposed maximum number of subdivisions is reached. The maximum number of subdivisions determines the voxel length along the i^{th} direction, according to the equation:

$$Length_i = \frac{\max(P_i) - \min(P_i)}{2^{r_i}} \tag{1}$$

where i=x, y, z and r^i is assumed to be the algorithm's resolution. It changes at each iteration, until the maximum number of subdivisions (2^{ri}) is reached along each direction. At the end of the computation, false state voxels are not considered so that the plot of true state voxels is able to represent a rough estimation of the component shape. If true state voxels include a sufficient number of points, best-fit algorithms can evaluate the local characteristics of the surfaces inside them. In [3] the sensitivity to the algorithm's resolution is discussed, highlighting that a satisfactory voxel's length must be chosen: (a) to limit the inclusion in one voxel of different features (like planes with chamfer, radii, edge, …); (b) to assume a proper resolution able to aggregate together voxels with similar local surface characteristics; (c) to build the whole surfaces that must be inspected. Adjacent voxels with comparable fitting characteristics are clustered together into the component global surfaces through a region-growing algorithm. The very first implementation searched only for voxels with planar surfaces. In [3], the automatic distinction between voxels that include planar surfaces from that including curved surfaces or different features, has been based on the analysis of the voxel variance frequency histogram. It is computed evaluating in every voxel the variance of the point distances from the associated best-fit plane. Local planes inside the voxels can be recognized consistently looking for the bin with the smallest variance, that now is achieved through an iterative algorithm. The variance frequency histogram is updated splitting its bins until the number of voxels, which are related to the minimum variance, becomes stable. This minimum variance is assumed to be the threshold required for finding the specific type of surface that is under investigation (planar or cylindrical). Fig. 1 shows an example of the derivative of the minimum variance found in the frequency histogram according to changes of the number of bins. The stable value, found increasing the number of bins, can be clearly seen. The component snapshots highlighted in the boxes show the improvements since the new threshold, found at 120 bins, is able to exclude cylindrical areas that locally can be approximated by a plane if the iterative algorithm is not applied (see blue points in areas 1,2,3,4 and 5). After the recognition of voxel with planar surfaces inside, local planes need to be aggregated, according to a region-growing algorithm, which is also able to recognize relevant plane directions of the component (Fig. 2(a).). Successively, in every plane direction distinct planar surfaces are found through a hierarchical clustering process considering physical connections of proximity among voxels that contain planes with similar fitting values (Fig. 2(b).). This process is stored in two adjacency matrixes, one manages the parallelism between couples of internal planes of voxels, and the other one the physical proximity of voxels. Each cluster is made by voxels, which are physically connected and contain parallel planes.

Then, for each cluster, a global best-fit plane is computed so that planar surfaces of the acquired component are reconstructed and their distances and tolerances can be measured (Fig. 2(c).).

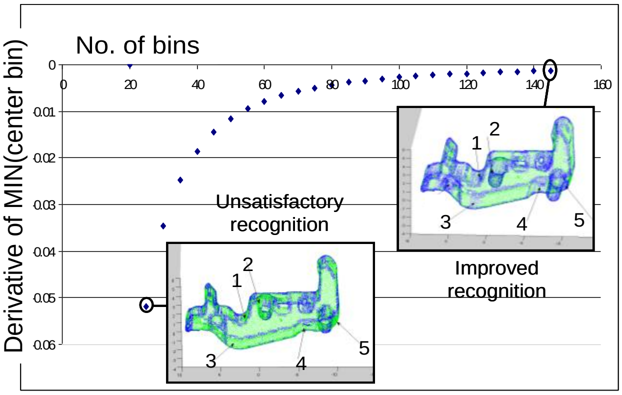

Fig. 1: Example of the derivative of the minimum variance changing the number of bin.

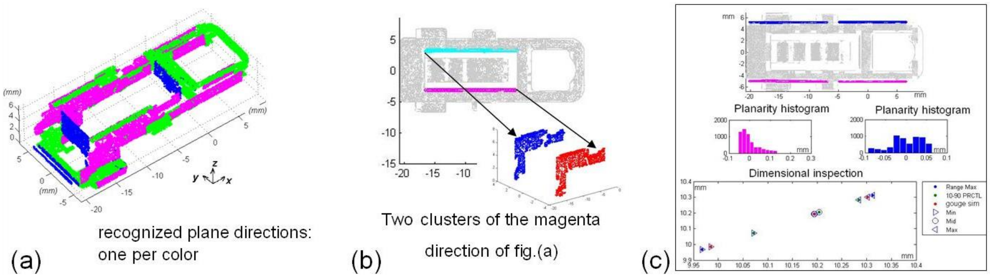

Fig. 2: (a) Region growing, (b) Two clusters of a planar set, (c) Example of tolerance inspection.

Recent new developments: cylinder partition and Intrinsic Reference System evaluation:

Fig. 3 on the left summarizes the actual workflow of the proposed approach considering the recent new developments, that are the cylinder partition and the IRS definition (in figure named as "Intrinsic Ref. System"). The cloud of points is acquired according to a reference frame that can be misaligned with the effective principal directions of the component or with CAD model. From the tolerance measurement point of view, an appropriate alignment could be necessary to localize datums or specific sets of functional planes according to drafting annotations. Usually the alignment of the cloud of points with the CAD model of the component is made interactively. To inspect a large number of components saving computation time, user-interaction should be avoided. For this reason we define a component reference system (also named Intrinsic Reference System, IRS) looking for the plane directions associated to the most populated sets of of voxels. In case of electromechanical components it may be considered a consistent reasoning since they are characterized by functional features on orthogonal planes or cylinders whose axes are parallel to the three principal directions of the component. Thus, it is clear that the most populated sets of voxels are the ones, which contain planar surfaces oriented along component's principal directions. From this the IRS computation derives by assigning as first reference axis the planar direction of the most populated set of voxels. Then the other two axes are found among the two subsequent more populated sets of voxels that are mutually orthogonal. The soundness of this procedure has been tested on different components as reported in [4]. The IRS has been always found and it is always associated to the most relevant surfaces of the component (in case of the axial-symmetric part of Fig. 4(a). it has the z-axis coincident with the central axis of the component). Nevertheless, when the entire inspection process will be definitively set up more accurate investigations have been planned to evaluate its consistency with the inspection procedure.

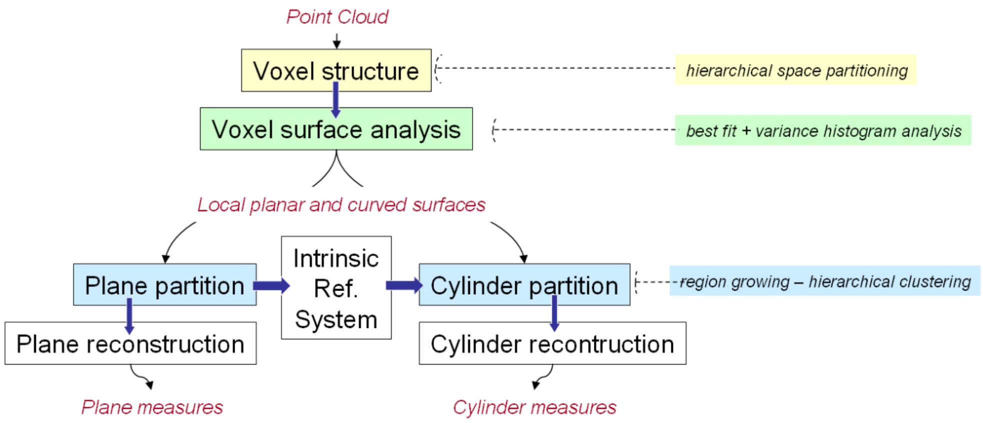

Fig. 3: Logical workflow of the proposed approach and applied methodologies (on the right).

Concerning the cylindrical surface evaluation and partition they have been conceived following the same steps of the plane analysis (best-fit and variance histogram analysis, region growing and hierarchical clustering). To simplify the fitting problem, we project the points inside every curved voxels on planes that are normal to the directions of the IRS' axes and located at the centroid of the voxel's points. This is consistent with the assumption that cylindrical features are oriented along principal directions of the components (the IRS) due to their function of latch or hinge. Moreover, it reduces the complexity of the fitting problem, allowing to deal with algorithms such as Taubin, Kasa or Levenberg-Marquardt (LM) [7], [11].

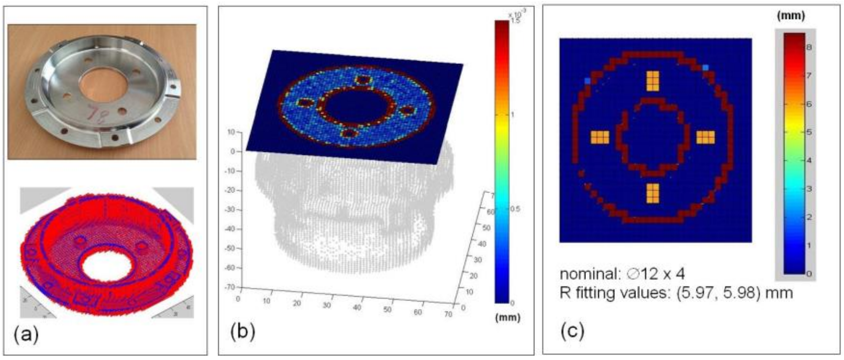

Fig. 4: (a) Axialsymmetric part, (b) Variance plot of the planar best-fit on a voxel section, (c) Radius fitting values computed on cylindrical voxels.

Fig. 4(b) and Fig. 4(c) show the variance histogram analysis and the cylindrical surface partition applied to the axialsymmetric component. Fig. 4(c) gives an example of how the applied best-fit algorithm works. It has been based on LM, assuming Kasa's result as first guess, final results evaluate a radius of about 5.98 mm versus a nominal value of 6.00 mm. Cylinder partition is made via region-growing and hierarchical clustering. Similarly, to the planar surface analysis, sets of cylinders and related clusters are found verifying the radius of the cylindrical elementary surface (R_i) to a specific radius (Rj) that represents the current seed of possible cylinder clusterization:

$$DR_{ij} = 1 - \frac{abs(R_i - R_j)}{R_j} < \varepsilon; \qquad \forall R_j \in S \tag{2}$$

where ε stands for the threshold assigned to accept R_i as member of the cluster whose R_j is the seed. If Eqn. (2). is not verified for all the j^{th} elements inside the set of seeds (S), R_i becomes a new member of S. Doing so at the end of the region growing – hierarchical clustering procedure cylinder clustering is done according to every significant radius Rj of the component that are found in S. The proposed paper and the presentation will show the capability of the proposed automation through a test-case that represents a real electromechanical component with planes and various cylindrical features. It is a latching lever shown in Fig. 1 and utilised in electromechanical switches of electric panels.

Conclusions:

Concerning the criterion for defining which are planar or cylindrical voxels, the adoption of an iterative analysis of the variance frequency histogram seems to mitigate the arbitrary assignment of thresholds, although more accurate sensitivity analysis must be done to evaluate its robustness. Cylindrical surface evaluation made coupling Kasa and LM algorithms is effective for the number of points typically found in our voxel structure. The definition of the IRS helps to avoid CAD model alignment, that becomes unnecessary for the measurement. Voxel resolutions represents the intrinsic limit of the procedure but also its strength to classify surfaces digitized with a large number of points.

References:

[1] Attene, M.; Falcidieno, B.; Spagnuolo, M.: Hierarchical mesh segmentation based on fitting primitives, The Visual Computer, 22(3), 2006, 181-193. http://dx.doi.org/10.1007/s00371-006-0375-x

[2] Beiter, K. A.; Ishii, K.: Incorporating dimensional requirements into material selection and design of injection molded parts, ANTEC, Conference Proceedings, 3, 1997, 3295-3299.

[3] Bici, M.; Campana, F.; Petriaggi, S.; Tito, L.: Study of a point cloud Segmentation with Part Type Recognition for tolerance inspection of plastic components via Reverse Engineering, Computer Aided Design and Application, 11(6), 2014, 640-648. http://dx.doi.org/10.1080/16864360.2014.914382

[4] Bici, M.; Campana, F.; Trifirò, A.; Testani, C.: Development of automatic tolerance inspection through Reverse Engineering, Proceeding of Metrology for Aerospace (MetroAeroSpace), 2014 IEEE, 29-30 May 2014. Italy http://dx.doi.org/10.1109/MetroAeroSpace.2014.6865903

[5] Busick, D. R.; Beiter, K. A., Ishii, Kos: Design for injection molding: Using process simulation to assess tolerance feasibility, (1994) Computers in Engineering, Proceedings of the International Conference and Exhibit, (1/-), pp. 113-120.

[6] Gao, J., Gindy, N.; Chen,X.: An automated GD&T inspection system based on non-contact 3D digitization, International Journal of Production Research, 44(1), 2006, 117-134. http://dx.doi.org/10.1080/09638280500219737

[7] Kasa, I.: A circle fitting procedure and its error analysis, IEEE Transactions on Instrumentation and Measurement, IM-25(1), 1976, 8-14. http://dx.doi.org/10.1109/TIM.1976.6312298

[8] Keller, P.; Bertram, M.; Hagen, H.: Reverse engineering with subdivision surfaces, Computing, 79(2-4), 2007, 119-129. http://dx.doi.org/10.1007/s00607-006-0191-1

[9] Martínez, S.; Cuesta, E.; Barreiro, J.; Álvarez, B.: Analysis of laser scanning and strategies for dimensional and geometrical control, Int J Adv Manuf Technol, 46, 2010, 621-629. http://dx.doi.org/10.1007/s00170-009-2106-8

[10] Shamir A.: A survey on Mesh Segmentation Techniques, Computer Graphics Forum, 27(6), 2008, 1539–1556. http://dx.doi.org/10.1111/j.1467-8659.2007.01103.x

[11] Taubin, G.: Estimation of planar curves, surfaces, and nonplanar space curves defined by implicit equations with applications to edge and range image segmentation, IEEE Transactions on Pattern Analysis and Machine Intelligence, 13(11), 1991, 1115-1138. http://dx.doi.org/10.1109/34.103273