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AN IMPROVEMENT OF FIXTURELESS INSPECTION FOR NON-RIGID PARTS BASED ON FILTERING SAMPLE POINTS

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ABSTRACT

Geometric inspection of non-rigid (flexible) parts in free-state can aid manufacturers to automatically and inexpensively improve quality by detecting defects on manufactured parts. Non-contact optic data acquisition devices (scanners) are used to measure point clouds on the boundary of manufactured part in free-state and compare it with its nominal computer aided design (CAD) model in a common coordinate system. In the case of non-rigid parts, deformation during free-state inspection, mostly due to weight and to residual stresses, causes specific problems since this deformation has to be distinguished from defects. In this study the *generalized numerical inspection fixture (GNIF)* method is applied to generate a prior set of corresponding sample points between CAD and scanned models. These points are then used to deform the CAD model to conform to scanned data, through finite element non-rigid registration. Corresponding sample points generated using GNIF are evenly distributed over both models. Therefore, some sample points may be located on defects, which makes that these defects cannot be measured accurately. In this paper we introduce a method, aimed at automatically removing these sample points, which is based on von Mises stress and curvature criteria. Once removed, these points are no longer used in non-rigid FEA registration, which makes that associated defects can be identified and measured accurately.

KEYWORDS: Geometric inspection, Non-rigid parts, von Mises stress, Discrete curvature, GNIF, FEA, Mesh modification.

INTRODUCTION

Competitive markets imply high quality standards for manufactured parts, which requires setting up fast and accurate geometric and dimensional measurement methods. Beholden to the improvements in computer graphics and optic scanners, manual and tactile methods of measurement and inspection have been replaced by Computer Aided Inspection (CAI) methods. Manufactured parts are automatically scanned as point clouds and this scanned data is compared with the nominal CAD model in a common coordinate system. This allows identifying and measuring defects on these parts. Non-rigid (flexible) manufactured parts, e.g. parts with a very thin thickness (if compared with the other dimensions) deform to an extent in free-state which is beyond the dimensional and/or geometrical tolerances on the designed drawing. Parts are only subjected to gravity during free-state inspection and, as shown in Fig. 1-b, a non-rigid part deforms due to its own weight and/or the release of residual stresses.

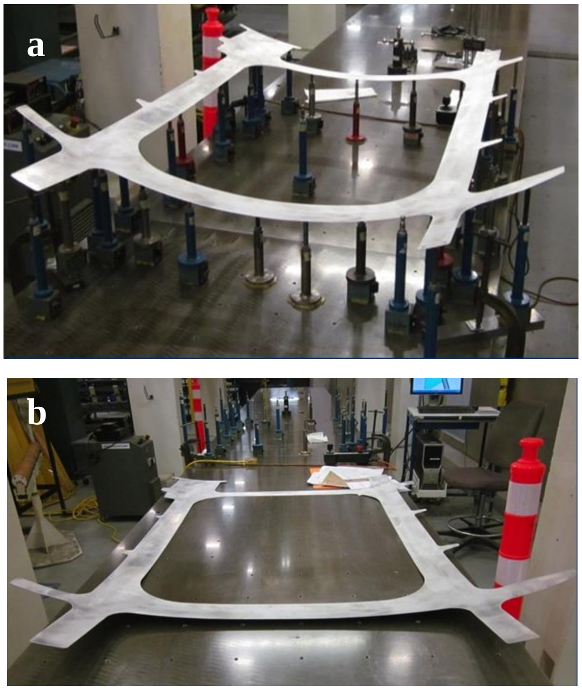

Figure 1: Compliance behavior of a non-rigid aerospace panel, a) constrained on its inspection fixture, b) in free-state inspection. [1].

Undesired dimensional and geometric deviation of non-rigid parts in free-state can be compensated by mounting these parts on special embedding fixtures. However, in most cases these fixtures are sophisticated and expensive increasing the lead time in the quality control process. Thus far, depending on the type of non-rigid parts, several virtual fixtureless inspection methods have been developed, among which methods introduced in [2-4]. In this study the generalized numerical inspection fixture (GNIF) method [5] is applied to find the intrinsic similarity between nominal CAD and scanned data in free-state. It is based on the assumption that deformation is isometric (deformation preserves geodesic distances). Based on this assumption and on fast marching algorithm for the calculation of geodesic distances on CAD and scan triangulations, GNIF generates corresponding sample points between the CAD and scanned models. In this purpose, generalized multidimensional scaling (GMDS) is a minimization algorithm that finds corresponding sample point on CAD model which has the minimum geodesic distortion respect to its sample point on scanned data. Corresponding sample points are used to deform the CAD model conforming to scanned data by means of FEA and introducing displacement vectors on the CAD sample points. Bringing the deformed CAD and scanned model in a common coordinate and making a comparison between them, defects will be detected and can be measured.

Since corresponding sample points are evenly distributed all over the CAD and scanned model, some samples can be located on defect areas. It causes inaccurate measurement of defects because sample points on a defect deform the CAD model to take the defect shape. In this paper, two filtration methods are explained to automatically remove sample points on defect areas. The first one is based on von Mises stress criterion and the other applies difference between discrete curvatures on CAD and scanned model. Since the removed sample points will no more be applied in FEA, the CAD model will deform to simulate only the elastic deformation of scanned part due to its flexibility in free-state but not the deviated defects. This improves the measurement of possible defects during inspection of manufactured parts.

FILTERING GNIF SAMPLE POINTS

The generated corresponding sample points by GNIF method are evenly distributed over the CAD and scanned model, and applying FEA with displacement vector on CAD sample points deforms the CAD model to conform to scanned data. Since displacing the CAD sample points on defect areas impels the CAD model to take the shape of defects on scanned data, it is required to estimate the defect areas beforehand and filter these CAD sample points from FEA boundary conditions for improving defect measurement.

Study of von Mises stress contour on the CAD model deformed by FEA applying all the generated sample points, clarifies that the existence of defects increase locally the stress value in the defect areas. Defining a threshold for the stress value provides an estimation for the position of defects, in other words, defects are located where the stress value is higher than the defined threshold value.

Meanwhile, comparing the curvature map between the CAD and scanned model shows that defects cause significant difference between the models curvatures. This can also be utilized as a criterion to detect defects and to filter sample points on the defect areas. For this purpose, the principal discrete curvatures on the CAD and scanned triangulation are calculated by Eq. (1) and Eq. (2) for maximum and minimum curvatures respectively.

$$K_1(p) = K_H(p) + \sqrt{K_H^2(p) - K_G(p)} \tag{1}$$

$$K_2(p) = K_H(p) - \sqrt{K_H^2(p) - K_G(p)} \tag{2}$$

Where K_H is the mean curvature and K_G is the Gaussian curvature. The mean and Gaussian curvatures are also discretely calculated by the Gauss-Bonnet scheme [6].

CASE STUDY

The case study herein is an aerospace aluminum panel of approximately 1.5 m length to 1 m width and 1 mm thickness. As shown in Fig. 1, the CAD model is schematically compared with the scanned mesh which is deformed (representing the free-state deformation of non-rigid part) and is included three defects which their height is measured as 1 mm for bumps No. 1 and 3, and also 1.5 mm for bump No. 2.

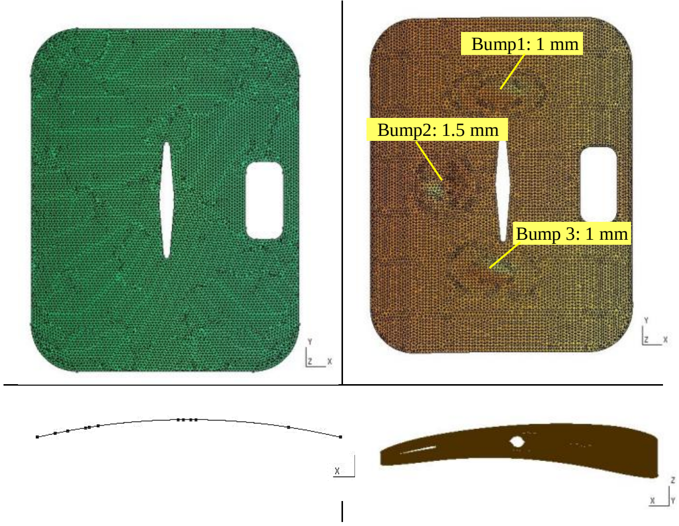

Figure 1: Mesh triangulation; Left) nominal CAD model, Right) scanned mesh (deformed and included three defects).

The corresponding sample points, which are generated by GNIF method as shown in Fig. 2, are inserted into the CAD mesh of the case study by incremental Delaunay triangulation method which is illustrated schematically in Fig. 3.

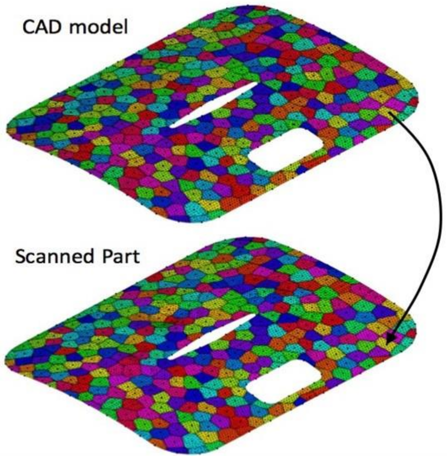

Figure 2: Corresponding sample points generated by GNIF method between the CAD and scanned models.

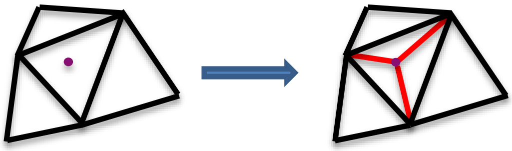

Figure 3: Violet point is inserted into a mesh by incremental Delaunay triangulation method.

The inserted sample points into the CAD mesh are evenly distributed all over the model which are depicted in Fig. 4 by green color for triangles sharing the sample points.

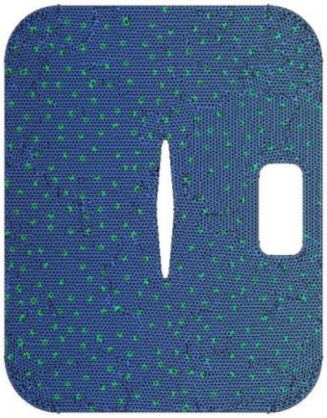

Figure 4: The inserted sample points are evenly distributed over the CAD mesh (green triangles).

Applying FEA to displace the sample points on the CAD model toward the position of their corresponding sample points on the scanned mesh, the CAD model is deformed to conform to scanned part. Bringing both deformed CAD and scanned model in a common coordinate and comparing the models, defects are measured as shown in Fig. 5. The defects are measured for bump No. 1 to 3 as 0.13 mm, 0.19 mm and 0.32 mm which has respectively 87%, 87% and 68% error comparing to the actual measured defects.

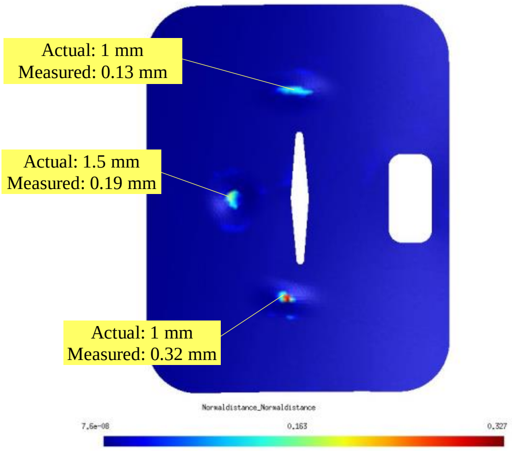

Figure 5: Defects measurement applying all sample points.

Comparing to the actual defect size, the measured defects include significant errors and it is required to filter the CAD sample points located in defect areas. The GNIF method has an inherent inaccuracy during generating corresponding sample points which causes high stress values distributed all over the deformed CAD model. However, as shown in Fig. 6, the von Mises stress value on defect areas are also locally higher than the other zones. The stress variation on defects are different from noise stresses caused by GNIF error. Determining the median value of von Mises stress range (3000 MPa) as threshold for this model, the defects are indicated on areas with von Mises stress higher than the threshold value.

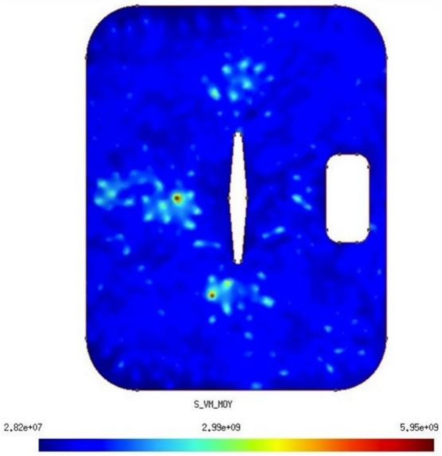

Figure 6: von Mises stress (range: 28 – 6000 MPa) for deformed CAD model applying FEA to conform to scan data.

Removing sample points where the stress value exceed the threshold value and applying displacement vectors by FEA on the remained sample points, improves the measurement of defects for bumps No. 1 to 3 as 0.22 mm, 0.45 mm and 0.67 mm which has respectively 78%, 70% and 33% error compared to actual defect sizes.

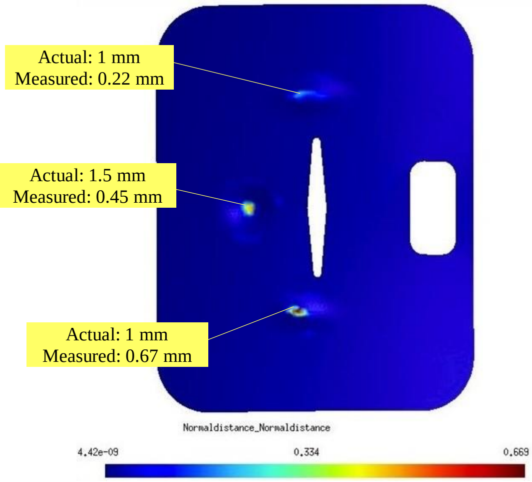

Figure 7: Defects measurement after filtering the sample points by von Mises stress criterion on defect areas.

Even though the filtration method by stress criterion improves the measurement of defects size, the defect measurement is more accurate as applying curvature criterion for sample point filtration. The difference of discrete principal curvatures between the CAD and scanned model is utilized to detect the defect areas. Fig. 8 illustrates, as an example, the discrete maximum curvature map calculated on the CAD and scanned mesh for the case study model. After calculating the difference of principal curvatures on CAD model compared to scanned data, the quarter of maximum value for curvature difference is applied as the threshold value.

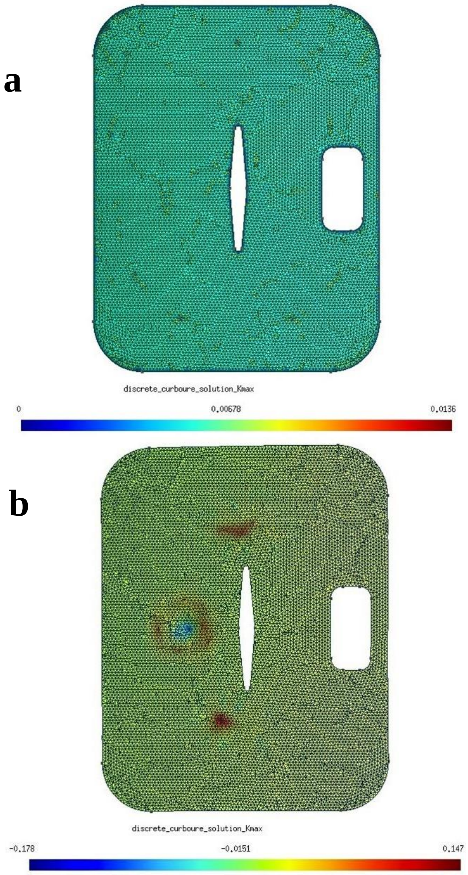

Figure 8: K_{max} curvature on a) the CAD mesh (range: 0. - 0.014 mm^{-1}), b) the scan data (range: -0.178 - 0.147 mm^{-1}).

Removing the corresponding sample points located on the CAD model which exceeds the threshold value provides a much more accurate defect measurement as shown in Fig. 9. The defects are measured for bumps No. 1 to 3 as 0.75 mm, 1.49 mm and 0.80 mm which has respectively 25%, 0.7% and 20% error comparing to actual defects size.

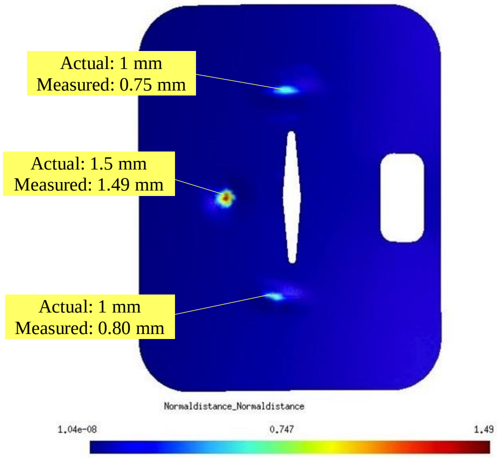

Figure 9: Defects measurement after filtering the sample points on defect areas by curvature criterion on defect areas.

CONCLUSIONS

In this study the fixtureless inspection of non-rigid parts applying the GNIF method is improved by augmenting the measurement accuracy of defects on the manufactured parts. Applying stress and curvature criterions, sample points associated to defect areas can automatically be removed which result in a deformation of CAD model to conform to scanned data except on defects. This development improves the GNIF method to automatically filter sample points and only apply those which are required to simulate the compliance deformation of part in free-state, and measure defects more accurately. The implementation of this method can be generalized by defining the threshold values automatically for stress and curvature criteria, and also the measurement accuracy can be improved by implementing successively the stress criterion after curvature criterion. Meanwhile, the method needs to be checked on cases which include global defects comparing to the defects used in the case study.

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