Some Investigations on Geometric Conformity Analysis of a 3-D Freeform Objects Produced by Rapid Prototyping (FDM) Process

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Abstract - Rapid prototyping technology is widely used to fabricate 3-D objects with all features of a design using Computer Aided Design (CAD) model. The final fabricated object with rapid prototyping technique has to be evaluated regarding the extent of its closeness to CAD model. Geometric conformity analysis has to be used in determining a measure of the geometric deviation between designed and fabricated 3-D models. In this paper evaluation technique is used to provide an aggregate measure of overall geometric deviation between designed free formed surface and its fabricated geometries using Fused Deposition Modeling (FDM) technique. This approach is typically utilized for large or more complex assemblies such as vehicle interiors and exteriors and full scale aircraft etc. Computer Aided Inspection with CMM aims at development of suitable methodology so as to convert data obtained from CMM to convenient formats to measure dimensional and form errors of freeform surface objects. The present work used in additive manufacturing with the newer methodology of inspecting in rapid product development also.

Key words - *Volumetric error; deviation analysis; freeform surface; reverse engineering; build orientation.*

I. INTRODUCTION

The development of a new product is an iterative process that includes product prototyping for experimental evaluation and design modification. Reverse engineering is one of the solution to convert the first conceptualization shape that will be successively coded in a mathematical expression with the help of physical model by rapid prototyping technique. The intermediate product stage of this conversion is reverse engineering. The reverse engineering (RE) process can be defined as process that results in the creation of mathematical model from a physical one. RE allows capturing and digitizing object surface geometry.

Surface point localization and reverse engineering techniques are capable of digitizing the geometric characteristics to create a complete mathematical model [1]. However, the digitization tends to pickup redundant points on relatively flat surfaces or in regions of constant curvature. If the surface is complex in shape with freeform features, a very accurate model is required [2]. The use of CMM is essential to manipulate the data for its successive valuation. Evident errors are common while comparing physical object with surface model.

The scanning of the object is essential in acquiring the digitization data. The acquisition pitch should be varied in relation with the complexity of the object shape to shorten the digitization time. It is also essential to have another scanning step. In the second step, it allows to define the boundaries for the surface [3]. This permits the model to work in an ordered set of planes instead of complex 3-D space. The standard deviation measurement of overall uncertainty can be evaluated using analytical expression. As a consequence of this, the developed algorithm should provide evidence of those zones of wide variations in curvature that needs exhaustive curvature analysis. These areas should be further investigated by a more accurate measuring device with smaller dimensional features.

It is essential to built accurate rapid prototyping (RP) parts without sacrificing from the efficiency of rapid prototyping. The dimensional inspection of freeform surfaces are essential in RP with high precision and complex design to corresponding as built parts for design verification, quality inspection, process improvement and error correction[4].

The most common source of error in RP processes are categorized into mathematical error, process related error and material related error. The errors involved during the data preparation stage are identified as tessellation, slicing orientation and location. Facet approximation and staircase effect also belong to data preparation errors. Principle process related error is shrinkage and distortion using the material. It is very important to understand the error distribution and error transfer mechanism in order to asses, predict and control the final geometric accuracy of the part. Error interaction between the data preparation and fabrication process are equally important. Fabrication process errors are machine path control and platform control accuracy, fixture stability, material feed uniformity, part thermal distortion etc. all these errors in combination are called disturbance error.The total volumetric error in a part will be different at different orientations because of the layer building process. The orientation of a RP part affects volumetric error. Orienting a part in the optimal direction will give a relatively smaller angle between the facets and build direction that may result in a less volumetric error. With the same layer thickness, the number of layers also changes with the angle of orientation. The shrinkage is dependent on the shape and size of the part and hence linear scaling factor is commonly used which may not be applicable for freeform surfaces. Hence newer methods of calculating the volumetric error is used namely layer perimeter based and layer area based. The freeform curved surface has different features compared to regular cylinders and cubes. The freeform surface has a characteristic feature similar to pyramid inclined in the upright or down left position, having one of the surface parallel or perpendicular to the direction of the axis of the part that can have least volumetric error. This principle is being used while selecting the orientation of the body while depositing the material. As the present work involves freeform curve shaped body, surface is parallel or perpendicular to the surface with highest volumetric error occurs at 45^0 orientation and minimum error at an angle of 0^0 and 90^0, as area error is more at 45^0 orientation. The theoretical error approaches to zero at 0^0 and 90^0 orientation. Hence in the present work 90^0 built orientation of the material is taken.

The main objective of the present work is to utilize the digitized data to build a CAD model in preparing rapid prototyping product using FDM. This data is compared with the CAD data obtained for the produced part to get error data. The error data is used to modify the existing data of the surface to reduce the error of the final object.

II. METHDOLOGY

In the present work, symmetrical convex surface is taken to produce a 3-D CAD model of the physical object using CATIA software. The model is converted in to .STL file where data is stored in the form of triangular information. The .STL file will be supplied to the RP machine (FDM Vantage) The RP machine will convert .STL file information into sliced information with the help of machine software (insight) available in the RP machine. The sliced information will provide a basis for the movement of the nozzle tip in X, Y direction. With the movement of nozzle tip and machine table, the physical part is produced using ABS plastic material. The freeform surface of the sampled object which is produced is shown in Figure.1

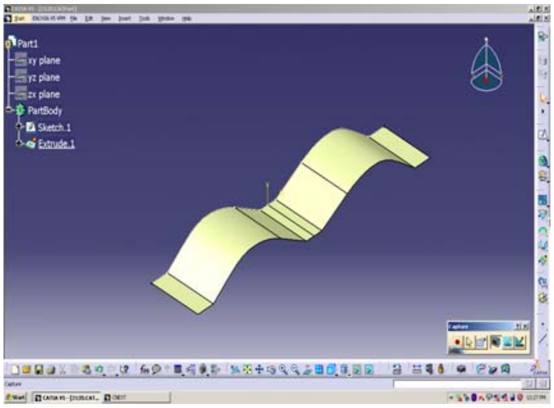

Fig. 1 : Geometrical model of the freeform surface

After producing the physical part by RP machine, it is measured with CMM (Mitutoyo make and Gantry type with an accuracy of 0.001mm), the experimental set up which is used for the measurement is shown in Fig.2

Fig. 2 : Measurement of Circularity error of the objects using CMM

By using CMM cloud point data of the produced part is generated. Further the cloud point data is processed to develop a CAD model which is compared with the original input CAD model for quality control by superimposing the original CAD model over the CAD model developed through the point cloud data of the object. Deviations that are found at different regions of the free form surface are analyzed and the average standard deviations are calculated. The average standard deviations of the whole set of inspection points are added to the original CAD model data to produce a new CAD model as an input to the RP machine.

In another setup the inspection data is divided into four zones (like Zone1, Zone2 etc.) and the average standard deviations of each zone is added to the concerned points of that zone in the original CAD model. This creates a new CAD model as input to the RP machine for producing another physical model. Both the objects produced by RP machine are further inspected with the CMM for comparison of their deviation errors. Methodology is explained in the form of a flow chart which is shown in Figure 3.

The inspected data is super imposed on to the original CAD model and deviations are noted for the surface of the object. The superimposed CAD model of the object is shown in Figure 4.

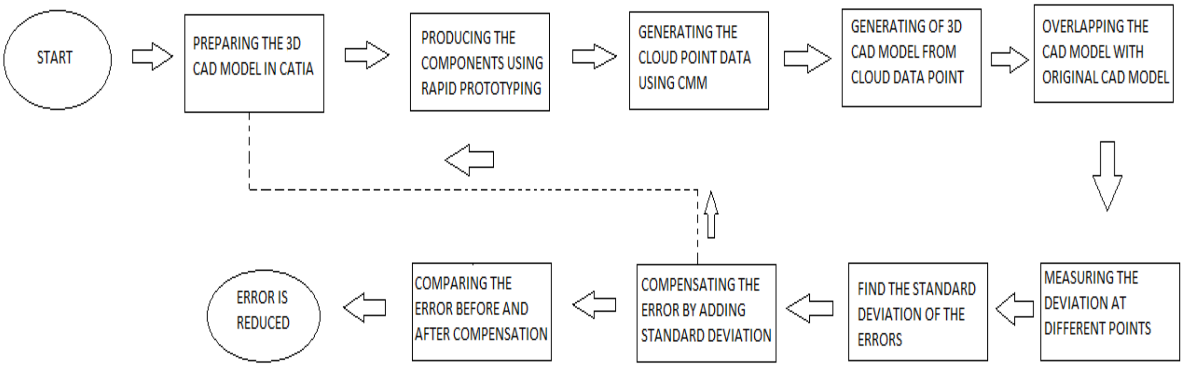

Fig. 3 : Methodology

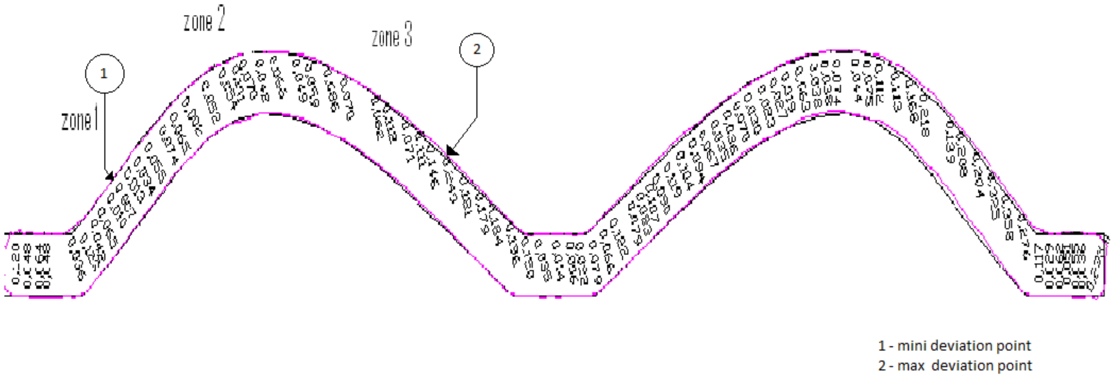

Fig. 4 : Observed deviations of the overlapped model

III. RESULTS AND DISCUSSION

After overlapping the CAD model generated from cloud point data on original CAD model the deviation values are observed. The deviations are continuously increasing in the ascending portion of the freeform surface till to a particular point where the slope of the curve changes at a faster rate in the zone (1) as shown in the figure 4. In this subsequent zone (2), slope changes slowly till its reaches its zenith. It is observed that the deviations are gradually decreasing till a point where the slope of the curve changes at a faster rate in the reverse direction. The maximum deviation observed in the over lapped model is 0.561mm and the minimum deviation value is 0.057 mm. In the reverse zone where slope is changing very fast, the deviations are found to be increasing. The deviations of the descending surface with the faster change in slope i.e zone (3) has higher deviations. It is also observed that the deviations are more whenever the sudden change from complex surface to flat surface takes place (0.123mm). However, the errors in the ascending surface are much more compared to the descending surface. Deviation values of the freeform surface at different zones are shown in Table 1. It is also observed that the deviations have been considerably reduced in the subsequent symmetrical zone of the model.

After adding the average standard deviation of the whole part to the original CAD model data creating new product, the inspected point cloud data was super imposed on the original CAD model data and deviation values of the freeform surface at different cross sections are shown in Table 2.

TABLE 1 : DEVIATION VALUES OF FREEFORM SURFACE AT DIFFERENT CROSS SECTION

Zone	X-coordinate	Y-coordinate	Deviation (mm)
Zone 1	5.364	3.057	0.201
	10.034	6.667	0.561
	14.774	9.325	0.543
	19.290	9.753	0.224
Zone 2	27.205	12.049	0.225
	35.016	13.964	0.417
	40.608	14.432	0.209
	46.157	12.241	0.093
Zone 3	54.695	9.956	0.263
	57.632	9.878	0.057
	64.129	7.439	0.126
	69.448	3.115	0.150

It is observed that the maximum deviation value is 0.276 and minimum deviation value is 0.042 and deviations are reduced by 15% while following the same pattern as explained above.

TABLE 2 : DEVIATION VALUES OF THE FREEFORM SURFACE AT DIFFERENT CROSS SECTION (UNIFORM COMPEMSATION)

zone	X-coordinate	Y-coordinate	Deviation
Zone 1	5.364	3.057	0.123
	10.034	6.667	0.034
	14.774	9.325	0.052
	19.290	9.753	0.042
Zone 2	27.205	12.049	0.071
	35.016	13.964	0.196
	40.608	14.432	0.079
	46.157	12.241	0.119
Zone 3	54.695	9.956	0.063
	57.632	9.878	0.113
	64.129	7.439	0.139
	69.448	3.115	0.476

In the second case the respective average standard deviation are added after dividing the surface in to three zones as mentioned above. Deviation values of the freeform surface at different cross sections with non-uniform compensation are shown in Table 3.

It is observed that the maximum deviation value is 0.32 and minimum deviation value is 0.029 and deviations are reduced by 40% when compared to original object (without compensation) and 30% with uniform compensation.

TABLE 3 : DEVIATION VALUES OF THE FREEFORM SURFACE AT DIFFERENT CROSS SECTION (NON-UNIFORM COMPEMSATION)

Zone	X-coordinate	Y-coordinate	Deviation
Zone 1	5.364	3.057	0.320
	10.034	6.667	0.041
	14.774	9.325	0.048
	19.290	9.753	0.061
Zone 2	27.205	12.049	0.062
	35.016	13.964	0.029
	40.608	14.432	0.098
	46.157	12.241	0.112
Zone 3	54.695	9.956	0.085
	57.632	9.878	0.117
	64.129	7.439	0.107
	69.448	3.115	0.054

IV. CONCLUSIONS

In this approach division of surface into three zones are made based on the deviation values. However the error will depend on slope curvature of the curve. Hence the deviation values are not following any definite pattern. Hence it is suggested that the deviation should be based on change in continuity of the slope or curvature rather than the deviation error This approach will needs further investigation to make the error behavior of freeform surfaces.

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