

Research Article

Experimental Investigation on Reverse Engineering of a Typical Freeform Surface using Portable Laser Arm Scanner

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Abstract

The current research work presents, methodology of Reverse Engineering technique using portable laser arm scanner and necessary design software. A case study of Reverse Engineering using laser arm scanner and CAD tool is presented considering a typical part which is machined on CNC mill from the given CAD model. The processes in reverse engineering technique, right from object digitization, CAD model reconstruction and error analysis (Deviation Analysis) are discussed. The reverse engineered CAD model was built using Non-Uniform Rational B-splines modeling techniques and error analysis was performed comparing the data points vis-a-vis with CAD points. The results manifested that the methodology generated low error CAD models that are suitable for future engineering development using computational simulation.

Keywords: Reverse engineering, freeform surfaces, deviation analysis.

1. Introduction

Design of freeform objects often involves the use of physical models at some stages in the design process (J.P.Kruth *et.al*, 1998). Initial conceptual and aesthetic design of object is often done with clay or wood. In order to produce actual functional object, this model must be converted to CAD model. The process is defined as reverse engineering since the CAD model is created from physical part, in contrast to the regular engineering process of manufacturing parts from a CAD model.

Reverse engineering is an extensive technology that enables creation of virtual model of a physical part (A.Durupt *et.al*, 2008). There are a number of application areas of Reverse engineering, including metrology, quality control, design, virtual reality, medical and surgical applications, and preservation of Cultural Heritage (A.Salmi *et.al*, 2014). Reverse engineering technique begins with the digitization of an object, which is acquisition of points (point cloud) pertinent to the part surfaces; consequently the point cloud can be converted into ‘.stl’ file format or imported directly into the software used for surfaces reconstruction.

Tamss Varady discussed on further work before general purpose reverse engineering becomes widely available. That includes improving data capture methods and calibration, coping with noise merging

views, coping with gaps in the data, reliable segmentation, fair surface fitting, recognizing natural or human-intended structure of the geometry of the object and finally ensuring that consistent models are built (Tamss Varady *et.al*, 1997). Antonio Piratelli developed Computer-Aided Design associated to large complex geometries like hydraulic turbine runners, applying reverse engineering techniques and Non Uniform Rational B-splines modelling (Antonio Piratelli *et.al*, 2009). A.Salmi, E.Atzeni claimed that Reverse engineering methodology is adequate to virtually reconstruct the geometry of three-dimensional CAD model of a casting from its physical equipment (A.Salmi *et.al*, 2014). J.P.Kruth reports on the incorporation of these geometric boundary conditions in the CAD modelling of free-form surfaces from a cloud of points with non-uniform rational B-splines (J.P.Kruth *et.al*, 1998). Yu Zhang succeeded in creating a CAD model of the die through processing of digitized data (Yu Zhang, 2003). Antonio Piratelli-Filho compared and found that laser scanner and CMM are most efficient methods to reverse engineer the objects in terms of accuracy and costs (Antonio Piratelli-Filho, 2014). R.J.Urbanc (2008) presented data analysis and model generation techniques for reverse engineering of rotary components such as shafts and rotary dies.

In the current work, a methodology to recover a freeform surface is proposed. It involves the digitization of freeform surface object using a portable laser scanner and the development of CAD models using Non-Uniform Rational B-splines modelling

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techniques. The deviation analysis is carried out comparing the data points with the respective CAD points.

2. Materials and Methodology

2.1 Study of Model

The study is based on reconstruction of freeform surfaces of a complex geometry. The component selected is appropriate for testing because the slope of the chosen surface changes continuously measured in the Cartesian coordinates, as shown in Figure 1.



Figure 1 Component used for reverse engineering process

2.1.1 Acquisition of raw point clouds

Digitization of the model was made with an active non-contact scanning process using a portable laser scanner (FARO) is shown in Figure.2. The acquisition system of points was controlled automatically by software of equipment (FARO CAM2 MEASURE). Multiple scans are done to acquire point cloud with complete data of all geometric features of the object. The digitized data was further exported in ASCII (.asc) format file type.



Figure 2 Data acquisition setup

2.2 Methodology

2.2.1 Merging Scans

When the area chosen is very big and the amount of data is large, multiple scans can be created for it. The fact is that many objects have details on the top and/or the bottom that cannot be captured in a single scan. The merge feature allows scanning an object multiple times from different angles and merging those scans to make a single point cloud and a complete 3D model. To merge the point clouds that are generated from the

multiple projects, external software like Cloud compare can be used which automatically processes and uses an algorithm to identify common or shared points in two or more scans. The algorithm samples the data and aligns the two into a single point cloud depending upon the relative proximity between them. Technically, any number of scans can be combined but it is observed that, after three the process becomes redundant. A typical merged scan is illustrated in Figure 3.

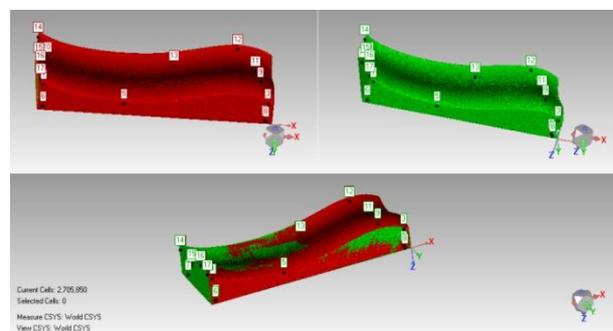


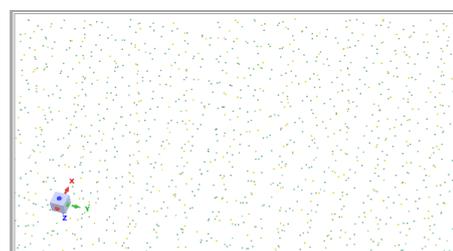
Figure 3 Merging of scans

2.2.2 Noise reduction

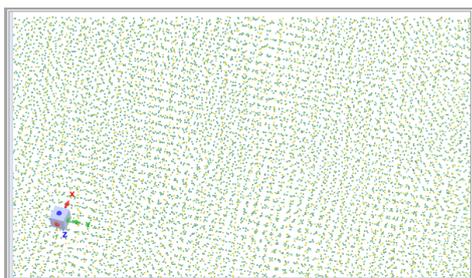
The scanner error often called noise is reduced by moving points to statistically correct locations. Noise can make sharp edges dull and make smooth curves rough. When this command is used, the result is a smoother, less noisy arrangement of points. Performing this process after removing outliers and portions of a scan that are not part of the object before using any of the sampling options will give good results. Either of freeform or prismatic of noise reduction procedures is selected based on the type of object being worked upon.

2.2.3 Sampling

Sampling is the process to reduce the number of points in scans by creating an evenly spaced set of points, regardless of curvature and original density. This point reduction technique is useful and widely recommended for objects with both flat and curved surfaces. This technique super-imposes a virtual three-dimensional grid over the selected object. When the sample is taken, the point that is closest to the centre of each grid is retained as shown in the Figure 4.



(a)



(b)

Figure 4 Point cloud data a) with sampling b) without sampling

2.2.4 Wrapping

Wrapping is a process of converting a point object to a polygon object. It is advantageous to wrap a point object because there are many refinements that can be performed on a polygon object that cannot be performed on a point object. The method works by maintaining a list of points from which the mesh can be grown and extending it until all possible points are connected as shown in Figure 5. It can deal with unorganized points, coming from one or multiple scans, and having multiple connected parts. It works best if the surface is locally smooth and there are smooth transitions between areas with different point densities. Triangulation is performed locally, by projecting the local neighbourhood of a point along its normal connecting the unconnected points.

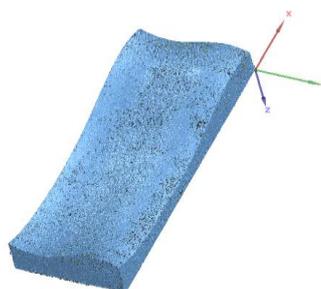


Figure 5 Wrapped model

2.2.5 Defects diagnostics

Diagnosing the defects and repairing is performed to find and fix various issues including Intersections, Non-manifold Edges, Small Components, Small Holes, Small Tunnels, Spike Edges and Spike Vertices.

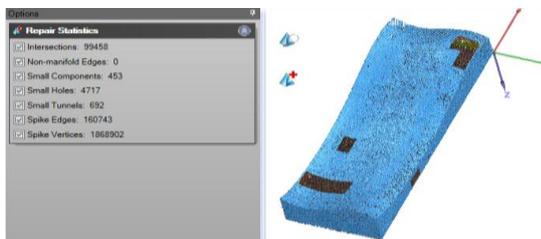


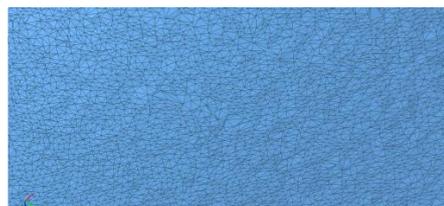
Figure 6 Model with defects statistics

2.2.6 Smoothing a Mesh Surface

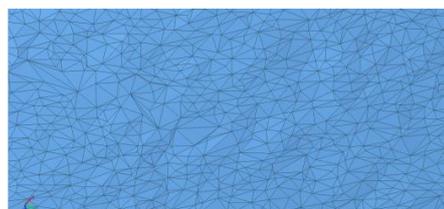
Smoothing a mesh surface can be done by minimizing crease angles between individual polygons (triangles), thereby improving the quality of polygon data. This process can be used effectively to reduce noise, such as an overall “tin foil” effect, or in any other area that has sharp spikes.

2.2.7 Simplifying Model (Reducing Triangles)

‘Simplify’ allows reducing the number of triangles in the object’s mesh without compromising surface detail or colour. It is useful when the object contains an excessive number of points. This process can be used on a selected area or on the entire object by specifying the target setting, so as to maintain the percentage of existing triangles.



(a)



(b)

Figure 7 Meshing a) without simplifying b) with simplifying

2.2.8 Filling Holes in Model

Filling operation can be done to fill specific holes or all holes in the model at the same time by the hole-filling technique with the commands listed below.

- 1) Curvature Fill: Specifies that the new mesh that fills the selected holes must match the curvature of the surrounding mesh.
- 2) Tangent Fill: Specifies that the new mesh that fills the selected holes must match the curvature of the surrounding mesh, but with more tapering than Curvature.
- 3) Flat Fill: Specifies that the new mesh that fills the selected holes is generally flat.

2.2.9 Alignment (3-2-1)

It establishes X, Y, and Z planes on both the Test and Reference objects and reorients the test object so that

its three planes match those of the reference object. A plane can be defined by three points, a perpendicular plane by two more points and a third plane perpendicular to those two planes is shown by one point. The alignment requires three points on the first shared plane of both objects, two points on a second shared plane of both objects, and one point on a third shared plane of both objects.

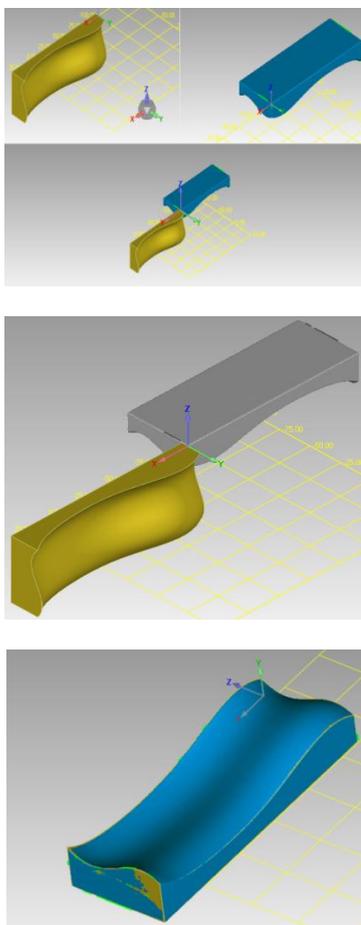


Figure 8 3-2-1 Alignment

2.2.10 Deviation/3D Compare

Deviation/3D Compare operation generates a three dimensional, colour-coded mapping of the differences between the selected objects. The Test object can be a point, polygon, or a CAD object.

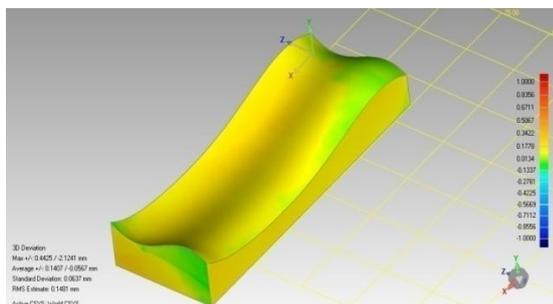


Figure 9 Three Dimensional Deviation Analysis

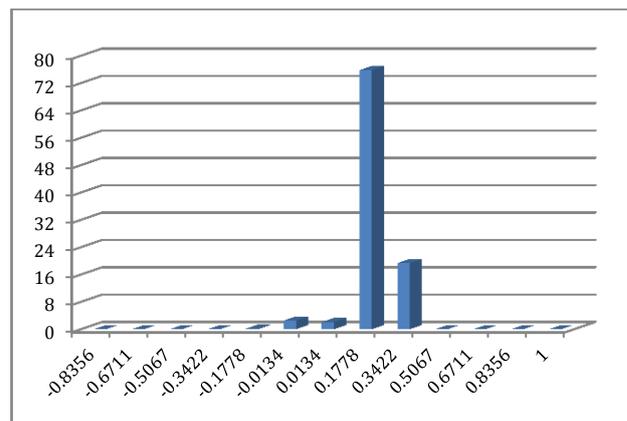
The reference object can be Polygon or CAD. If a portion of the Test object has insufficient data for valid comparison to the reference object, that portion of the result object will be gray. Deviations are reported as the shortest distance from the test to any point on the reference. It gives values like standard deviation, Root Mean Square Deviation, average deviation etc.

3. Results and discussions

When compared to the original CAD file 75.82% of points are within the deviation range of 0.0134 mm to 0.1778 mm, whereas 19.35% of points are in between 0.1778 mm to 0.3422 mm as shown in Table 1.

Table 1 Deviation Distribution

>=Min	<Max	# Points	%
-1	-0.8356	0	0
-0.8356	-0.6711	0	0
-0.6711	-0.5067	0	0
-0.5067	-0.3422	31	0.0103
-0.3422	-0.1778	450	0.1491
-0.1778	-0.0134	7676	2.5426
-0.0134	0.0134	6318	2.0927
0.0134	0.1778	228913	75.8239
0.1778	0.3422	58430	19.354
0.3422	0.5067	65	0.0215
0.5067	0.6711	0	0
0.6711	0.8356	0	0
0.8356	1	0	0
Out of Upper Critical		0	0
Out of Lower Critical		18	0.006



54.93% of points are in 1* Standard Deviation range and 23.08% of points are in -1* Standard Deviation range as shown in Table 2.

Table 2 Standard Deviation

Distribution (+/-)	# Points	%
-6 * Std. Dev.	455	0.1507
-5 * Std. Dev.	822	0.2723
-4 * Std. Dev.	2212	0.7327
-3 * Std. Dev.	8614	2.8533
-2 * Std. Dev.	31186	10.3299
-1 * Std. Dev.	69679	23.0801
1 * Std. Dev.	165845	54.9336
2 * Std. Dev.	22387	7.4153
3 * Std. Dev.	622	0.206
4 * Std. Dev.	42	0.0139
5 * Std. Dev.	37	0.0123
6 * Std. Dev.	0	0

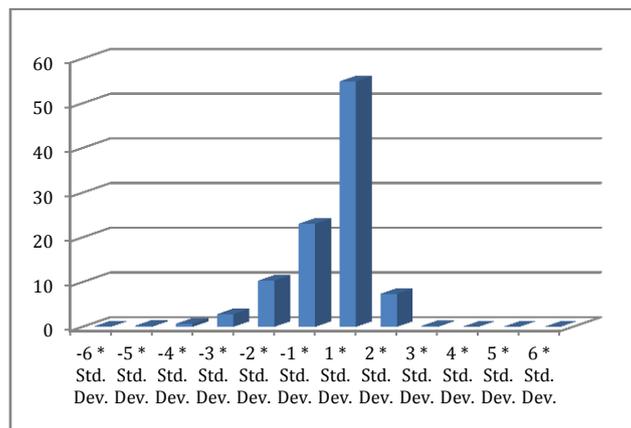


Table 3 Location Point Data

Name	Dev	Status	Upper TOL	Lower TOL	Ref X	Ref Y	Ref Z	Radius	Dev X	Dev Y	Dev Z
L1	0.1329	PASS	0.5	-0.5	10	-5	-45	1	0	-0.1329	0
L2	0.1375	PASS	0.5	-0.5	10	-5	-25	1	0	-0.1375	0
L3	0.1632	PASS	0.5	-0.5	10	-5	-5	1	0	-0.1632	0
L4	0.1295	PASS	0.5	-0.5	30	-5	-45	1	0	-0.1295	0
L5	0.1693	PASS	0.5	-0.5	30	-5	-25	1	0	-0.1693	0
L6	0.1354	PASS	0.5	-0.5	30	-5	-5	1	0	-0.1354	0
L7	0.1272	PASS	0.5	-0.5	50	-5	-45	1	0	-0.1272	0
L8	0.1563	PASS	0.5	-0.5	50	-5	-25	1	0	-0.1563	0
L9	0.1715	PASS	0.5	-0.5	50	-5	-5	1	0	-0.1715	0
L10	0.175	PASS	0.5	-0.5	70	-5	-45	1	0	-0.175	0
L12	0.1919	PASS	0.5	-0.5	70	-5	-25	1	0	-0.1919	0
L14	0.1627	PASS	0.5	-0.5	70	-5	-5	1	0	-0.1627	0
L16	0.148	PASS	0.5	-0.5	90	-5	-45	1	0	-0.148	0
L17	0.1838	PASS	0.5	-0.5	90	-5	-25	1	0	-0.1838	0
L18	0.1722	PASS	0.5	-0.5	90	-5	-5	1	0	-0.1722	0
L19	0.1442	PASS	0.5	-0.5	110	-5	-45	1	0	-0.1442	0
L20	0.1762	PASS	0.5	-0.5	110	-5	-25	1	0	-0.1762	0
L21	0.1848	PASS	0.5	-0.5	110	-5	-5	1	0	-0.1848	0
L22	0.169	PASS	0.5	-0.5	130	-5	-45	1	0	-0.169	0
L23	0.1748	PASS	0.5	-0.5	130	-5	-25	1	0	-0.1748	0
L24	0.1893	PASS	0.5	-0.5	130	-5	-5	1	0	-0.1893	0

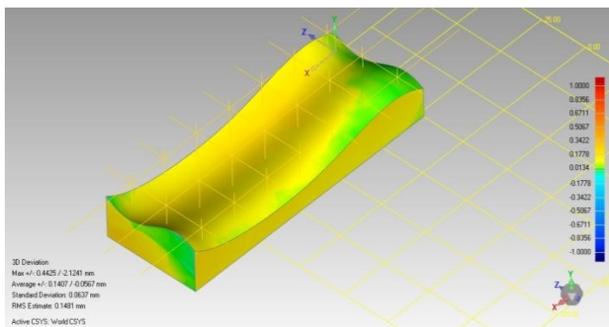


Figure 10 Location point sets at 21 points

Deviation status at 21 predefined points shown in Figure 10 is in between upper and lower tolerance range as depicted in Table 3.

The average and standard deviations are 0.0567 and 0.0637 respectively as shown in Table 4.

Table 4 Deviation Analysis

Reference Model	Free surface
Test Model	run1
No. of Data Points	301901
Tolerance Type	3D Deviation
Units	mm
Max. Critical	1
Max. Nominal	0.0134
Min. Nominal	-0.0134
Min. Critical	-1
Deviation	
Max. Upper Deviation	0.4425
Max. Lower Deviation	-2.1241
Average Deviation	0.1407 / -0.0567
Standard Deviation	0.0637

Conclusions

The deviation found from the analysis is following the normal distribution in consonance with other conventional process variation. The results generated a low error CAD model of the freeform surfaces. These are suitable for future engineering developments using computational simulations.

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