3D Scanning for Reverse Engineering- Technological Advancements, Process Overview, Accuracy Inspection, Challenges and Remedies

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Abstract – 3D scanning emerged as initial stage in reverse engineering for capturing surface geometry due to strides in speed and accuracy however capturing a three dimensional image digitally and converting to CAD model is not a doddle. 3D scanning technology has variations based upon principle used while capturing complete or partial measurement and varies with geometry and material properties of components each one associated with its own challenges. Reverse prototyping 3D printer is used to print a replica of the original object, and accurate general dimensions will be drafted and it is ensured that the 3D model has complete, water-tight surfaces and free from holes and misshaped areas, else the 3D printer may have problems in those areas. In this paper an industrial prototype with totally unknown dimensional parameters are scanned for reverse engineering. Once the 3D information is recorded by the scanner, it will send the information to a computer program and 3D model gets created from the scan but, the quality of final model depends upon surface characteristics, scanner parameters, scanning software as well as own artistic skills. Therefore data processing needs human intervention and poses a major challenge hence quality check and dimensional inspection analysis becomes ultimate necessity. For instance, based upon inspection analysis results alterations can be made in the model with the software and if needed scanning parameters are optimized and rescanning of prototypes and whole process is repeated till standard deviations are minimized within prescribed warning tolerance limits.

Index Terms – 3D scanning, digitization, surface topology, point cloud, reverse engineering, inspection.

1. INTRODUCTION

Reverse engineering can build intricate internal structures, parts inside of parts, and very thin-wall features just as simple as building a cube and thus provides a fast and inexpensive alternative for producing prototypes and functional models as compared to the conventional routes for part production.

Reverse engineering typically consists of four phases: data acquisition, preprocessing, segmentation and geometric model creation [1]. Systems such as structured light scanners paints the surface with light and are capable of measuring more than 70,000 points per second on a surface. Points collected can be plotted with the use of slightly offset sensors such that there is triangulation effect thereby providing dimensional locations in space [2]. The point form is known as "point cloud." The point cloud has complete coordinate address information in form of X, Y, Z coordinate along the 3 axis covering whole space for the points collected. This point cloud is then easily transformed into a CAD model supported in various native formats including CATIA, NX, AutoCAD, Solid Works, Pro/E and more.

1.1 Challenges of 3D Scanning

The object to be scanned and the environment affect scanner accuracy and impose limitations on scanning [3]. The material, geometry, surface and features in the scanned object can cause decreases in accuracy or prevent successful scanning completely. For example, specular materials are difficult to scan with lasers and discontinuous surfaces can yield scanning errors around edges. For this reason, it is difficult to define a single measurement to characterize accuracy. Relevant object features, such as corner points or edges, are not directly recorded; instead they have to be modeled from the point clouds in a separate process. While it is possible to record the same object several times from different observation points, it is impossible to record the very same points in these repeated surveys. Therefore, deviations can only be noticed after objects have been extracted from the point clouds and modeled [4]. New imaging techniques require expensive software and a lot of time to operate them [5]. Another bigger issue is scanning an object at high resolution and getting an exact scanning in the

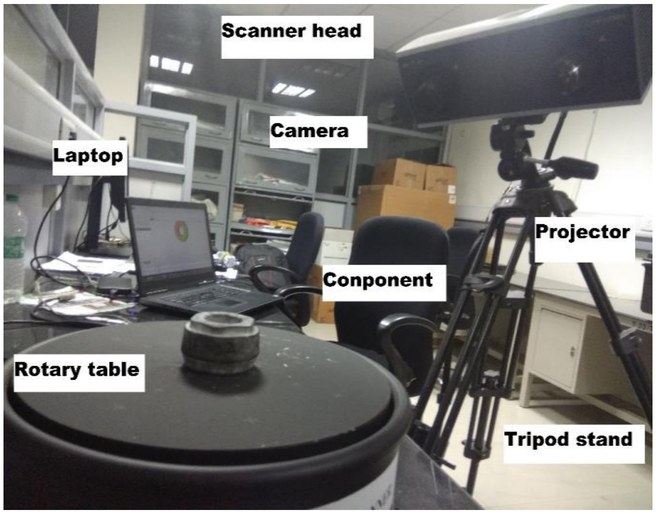
Field [6]. The reconstruction of surface geometry for transparent objects is complicated by the fact that light is transmitted through, refracted and in some cases reflected by the surface [7]. The right equipment and its matching software

are essential for 3D scanning in addition to the skilled people that are needed [8].

1.2 Objective

To study the effect of 3D scanning process parameters in data acquisition stage and post processing of scanned data to get the maximum similarity between the actual and CAD.

2. EXPERIMENTAL WORK



(a)

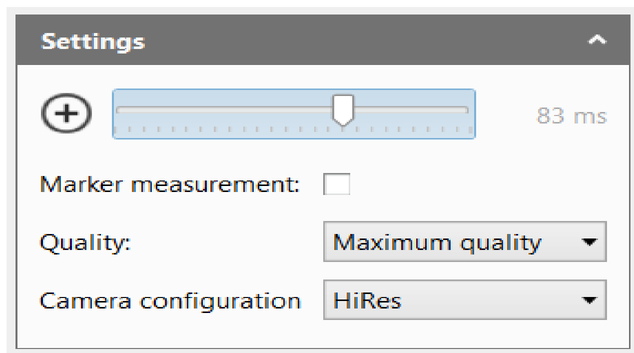
(b)

Figure 1 (a) industrial component (b) Steinbickler comet LED scanner

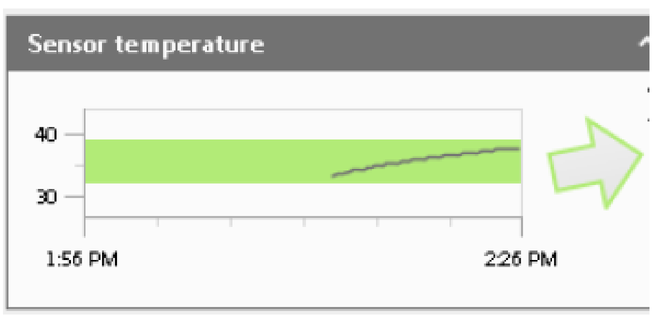
To acquire the topology or surface features of an object Steinbickler comet LED scanner with single camera technology with automatic object positioning from ZEISS was used and Colin3D is the simple to use available software for 3D data acquisition with comet. Colin3D offers a powerful software platform for operating the comet LED making measurements as well as editing and analysing the acquired data. Initially before starting the measurements calibration of measurement devices was done. In the calibration process, nine calibration measurements in different configurations are carried out using a calibration plate. From these measurements, the sensor calibration is then calculated and the result is displayed successful in the protocol. During the calibration, Changes in the ambient temperature, extraneous light influence and vibrations was strictly avoided.

2.1 Comet Sensor Settings

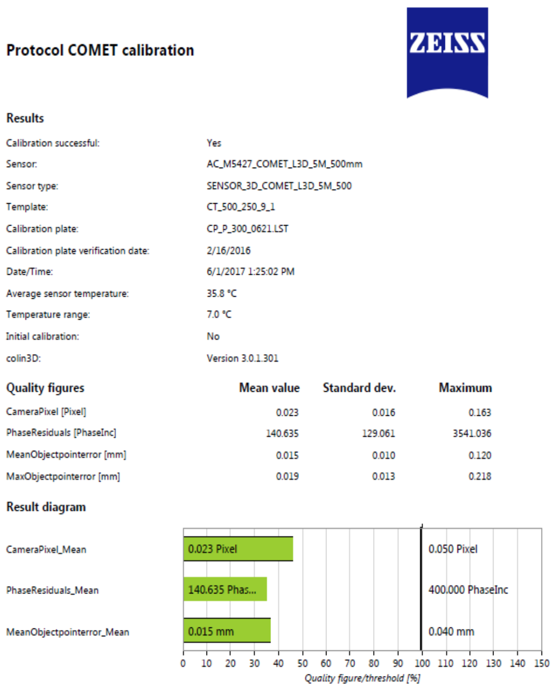
Measurement object is positioned, as exactly as possible, in the centre of the measuring volume located in the point of intersection between the fields of view of the camera and the projector. In order to get best scanned quality exposure time of 83 micro seconds was adjusted for the surface measurement where the image does not display any overexposed (red) or underexposed (blue) areas on the measurement object. Then quality parameter is specified in the quality list box based upon required quality for example the higher the requirements of the measurement quality, the fewer 3D data can be generated in critical areas on the object Vice versa for lower quality more data hence maximum quality is chosen in the quality list box for this industrial prototype because maximum quality is the main primary requirement. The full resolution of the sensor is used, providing maximum point density and quality therefore the HiRes mode is chosen in the Camera Configuration list box. Average sensor temperature was 35.8 ^{0}C at the time of calibration so measurements was taken when sensor temperature is within this temperature window. If the sensor is too cold (blue) or too hot (red), the specified accuracy cannot be guaranteed.



(a)



(b)



Protocol COMET calibration

Results

Calibration successful:	Yes
Sensor:	AC_M5427_COMET_L3D_5M_500mm
Sensor type:	SENSOR_3D_COMET_L3D_5M_500
Template:	CT_500_250_9_1
Calibration plate:	CP_P_300_0621.LST
Calibration plate verification date:	2/16/2016
Date/Time:	6/1/2017 1:25:02 PM
Average sensor temperature:	35.8 °C
Temperature range:	7.0 °C
Initial calibration:	No
colin3D:	Version 3.0.1.301

Quality figures	Mean value	Standard dev.	Maximum
CameraPixel [Pixel]	0.023	0.016	0.163
PhaseResiduals [PhaseInc]	140.635	129.061	3541.036
MeanObjectpointerror [mm]	0.015	0.010	0.120
MaxObjectpointerror [mm]	0.019	0.013	0.218

Result diagram

(c)

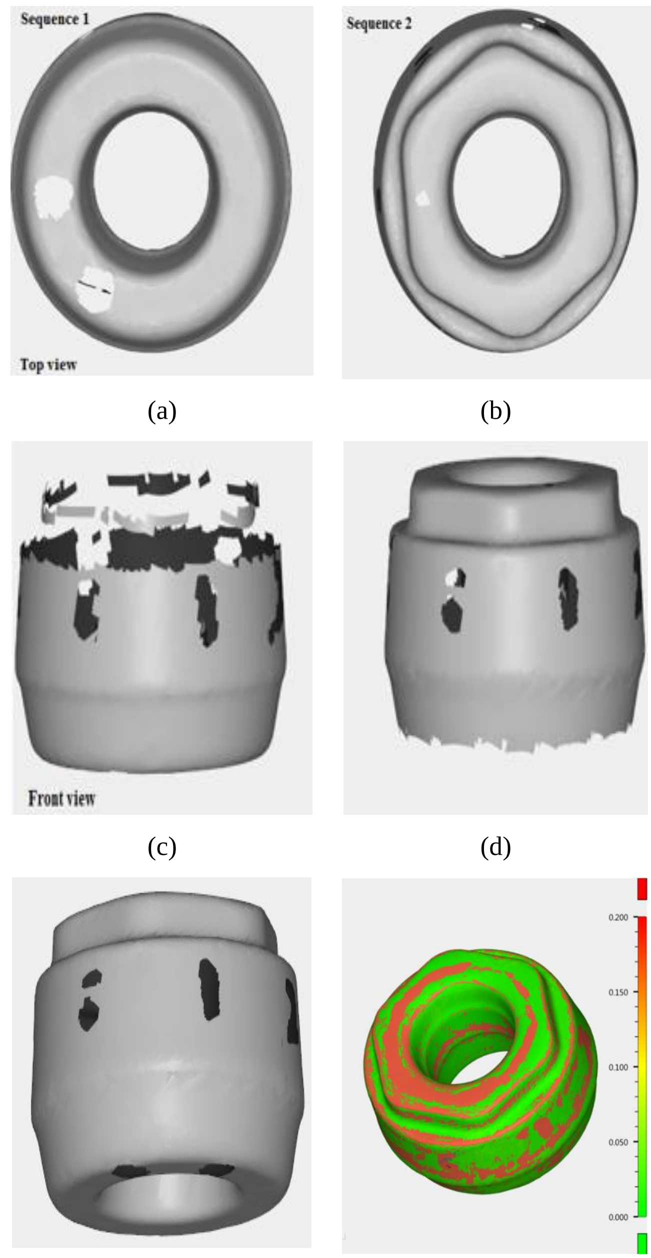
Figure 2 (a) Comet Settings (b) Sensor Temperature Tracker (c) Calibration Results

Table 1 Quality list for maximum quality

Quality List	Maximum Quality
Usage	High precision measurements
Material properties	Cooperative surface fewer reflection, sprayed surface
Noise level	Very low
Slightly overexposed areas are acquired	No
Gaps are filled automatically	No

2.2 Manual Alignments and global optimizations

Due to the axisymmetric nature of the object therefore rotary measurements was performed. This object is scanned in two sequence of 10 measurements each by defining the rotary table sequence in rotary measurements dialog box. At the end of the measurement sequence 2, the 3D data of this sequence had been aligned to the existing 3D data of sequence 1, therefore the Manual Alignment of two sequence was done. Global optimization is performed to improve the alignments of measurements with each other after all measurements had been made in order to achieve the best possible positions of all measurements in the overall formation. After optimizing the data the visualization of the gaps is updated and improvement of the alignment. The global optimization delivers information about the deviation in form of colour maps. The measurement data in the 3D viewer is coloured to allow a visual assessment of gaps. Location with no gaps are colour green and with increasing gaps the colour changes to red.



(a) (b) (c) (d) (e) (f)

Figure 3 (a) & (b) Top and Front View of sequence 1 (c) & (d) Top and Front View of Sequence 2 (e) Merging of Sequence 1 & 2 (f) Global optimization

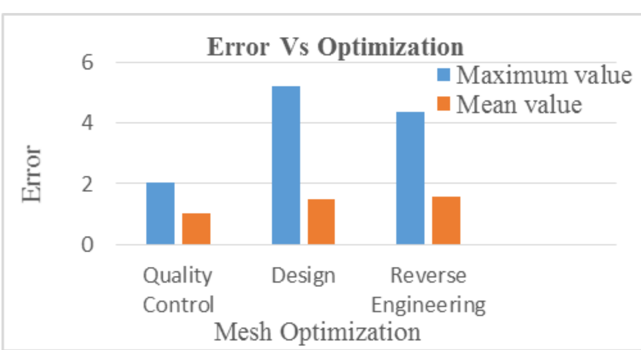
2.3 Data Editing and Mesh Creation

It was observed that the data points scanned are large in no and they are not evenly distributed this results in a large size of the file therefore the component in question contained 31,35,983 points. It is observed that some data that belongs to the surrounding not that of the measurement object was also captured therefore the editing of data was carried out in data editing option. Then mesh creation generates a triangle mesh of measurement points Polygon mesh is the first stage to convert the measurements data into the surface. Mesh is created by forming no of initial quads then its subsequent refinement by splitting of initial quads into four smaller quads. Depending on the application area there are four optimization options available for creating the triangle mesh: Quality assurance, Design, Reverse engineering and None. For each optimization option mesh is created and data results after each optimization is compared is the following table.

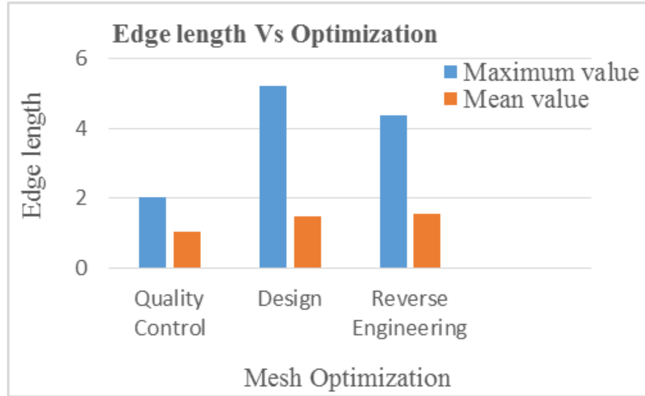
Table 2. Mesh Data after Optimization

Optimization	Quality Control	Design	Reverse Engineering
Error max value	0.058	0.143	0.132
Error mean value	0.004	0.022	0.020
Edge length (max)	2.040	5.22	4.376
Edge Length (mean Value)	1.033	1.474	1.562
No. of Triangles	61864	23962	32938

Figure 4 Optimization Setting



(a)



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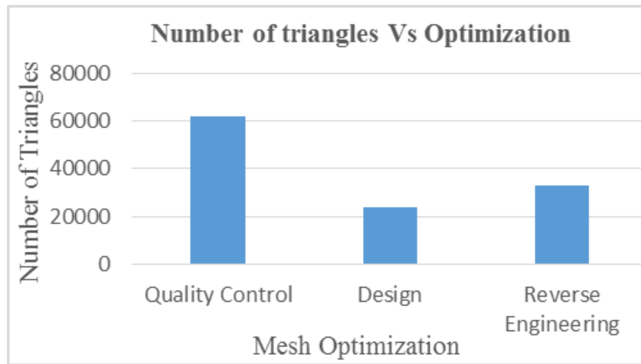
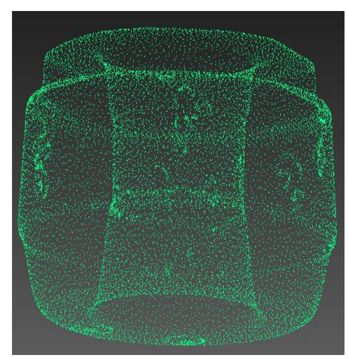


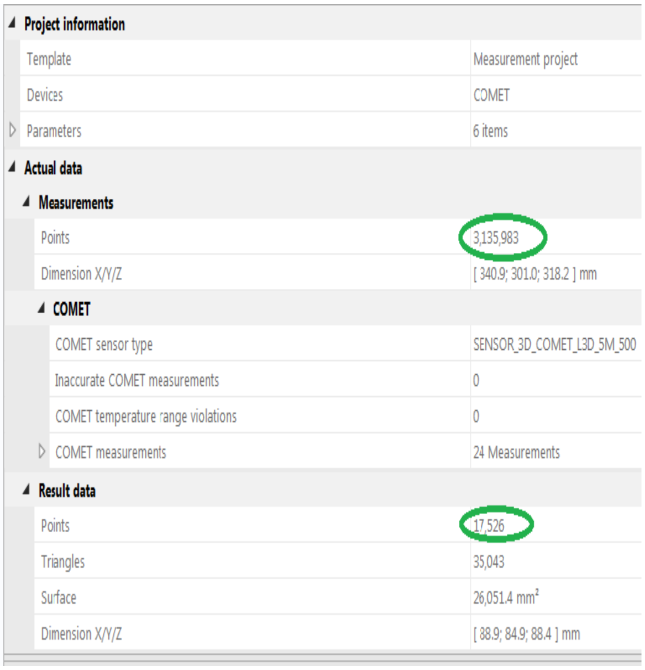
(c)

Figure 5 Graph of Mesh Data For (a) Error Vs Optimization (b) Edge Length Vs Optimization (c) Number of triangles Vs Mesh Optimization

(a)



(b)



(c)

Figure 6 (a) resulted triangle mesh (b) data point cloud (c) project information

The optimization options differ in the edge smoothing and data reduction for the created mesh. Here error represents the difference between point fittings to create a mesh and edge length are used for making sure that the mesh triangles are approximately of same size. Smaller values of edge length results in slower meshing and a higher polygon count with more equally sized polygons. Objective is to do reverse engineering therefore final reverse engineering optimized mesh is used for cad construction.

2.4 Construction of CAD in Geomagic Design X

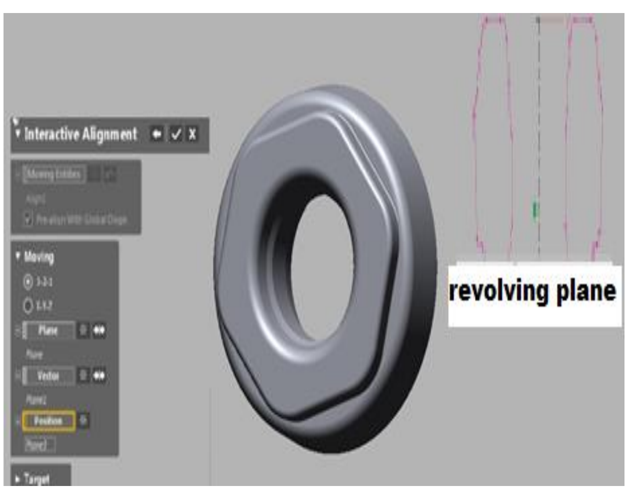


Figure 7 CAD construction in Geomagic DESIGN X

Geomagic is the professional engineering software that provides the best way to utilize 3D scanning for building cad models from 3D scan data. In Geomagic polyline fit on the contour of the model and B-spine is fitted on the contour of every slice to get the digitized model but this polyline fitting is totally depends upon operator artistic skills therefore it becomes the most tedious part of reverse engineering

3. RESULTS AND DISCUSSIONS

The CAD model prepared in Geomagic was compared with meshed model obtained from raw scanned data. The results for surface comparison, section comparison, boundary comparison & fold comparison are discussed. The results for each point is shown in terms of deviation with respect to x, y, z coordinates the coordinate values for the CAD model & the meshed model are shown as nominal and actual values respectively.

3.1 Surface Comparison

Results of the surface comparison of cad and the meshed model for six points including maximum and minimum values is shown in the figure:

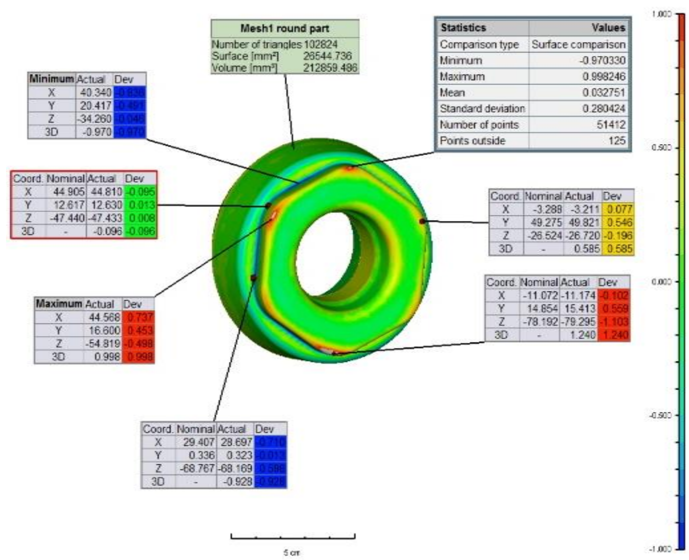
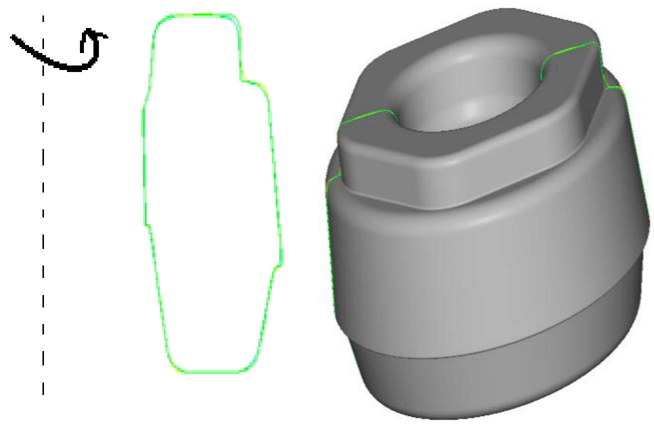


Figure 8 surface comparison between meshed and CAD model

The color chart indicates the match or mismatch between the CAD model and meshed model surfaces. The green color indicates accumulation of material and blue color indicates lack of material.

3.2. Section comparison

In a section comparison, nominal and actual scenes are cut by a plane same one for creating the model in Geomagic design x and the resulting lines are compared with one another. The easiest way of creation of section plane is to select a section at a plane that already exists in the scene.



(a) (b)

Figure 9 (a) revolving section **(b)** CAD model obtained after revolving of section

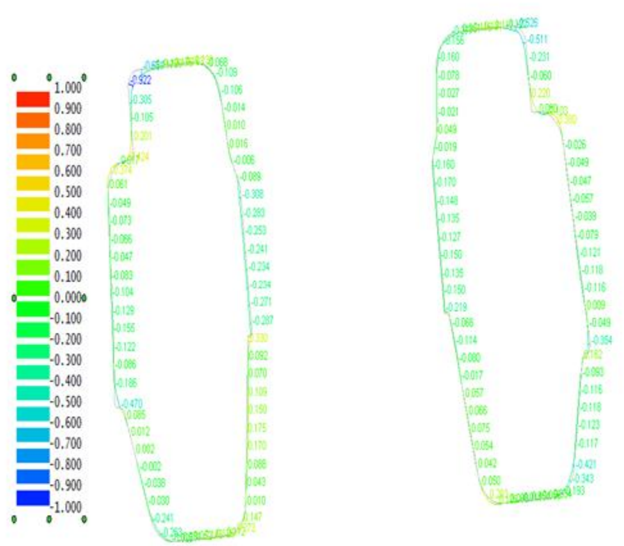


Figure 10 section comparison result for revolving section

The section comparison results in a group containing the following elements: the nominal section line as shown in black colour, the actual section line is shown in green colour and 3D text for displaying the deviations.

3.3. Boundary comparison

In a boundary comparison, the boundaries of the nominal and actual models was compared. As the result of this comparison, the determined deviations was displayed as needles of different colours extending from the boundaries. The figure below shows an example of such a needle diagram.

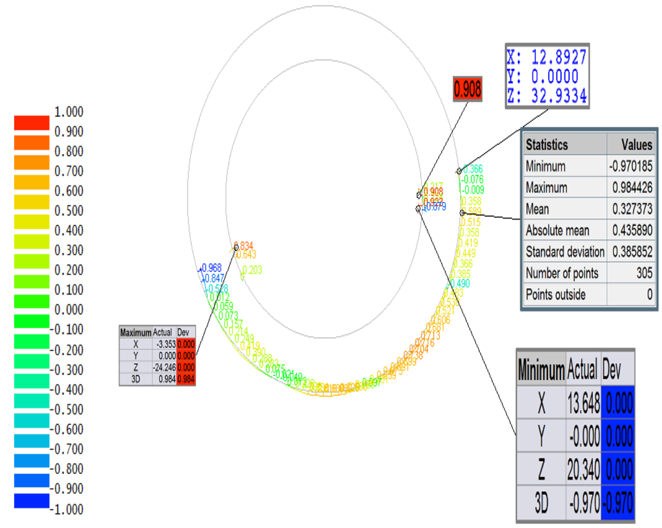
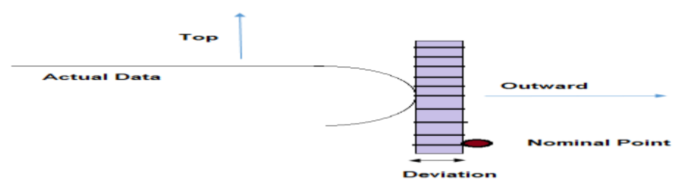


Figure 11 boundary comparison between meshed and CAD model

3.4 Fold Comparison

The deviation is determined only in the outward direction. The comparison is performed as shown in the following drawing:



(a)

The comparison was done and the viewer displays approximately the following representation:

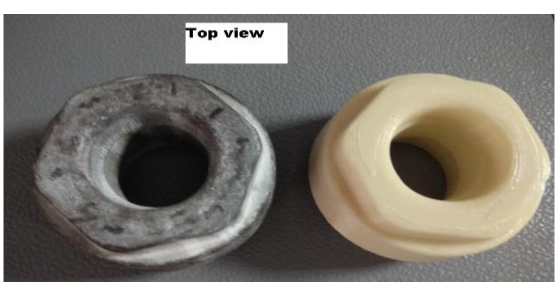
Figure 12 (a) deviation process for fold comparison (b) fold comparison result at six points

3.5 Remedies to Obtain Stable Results

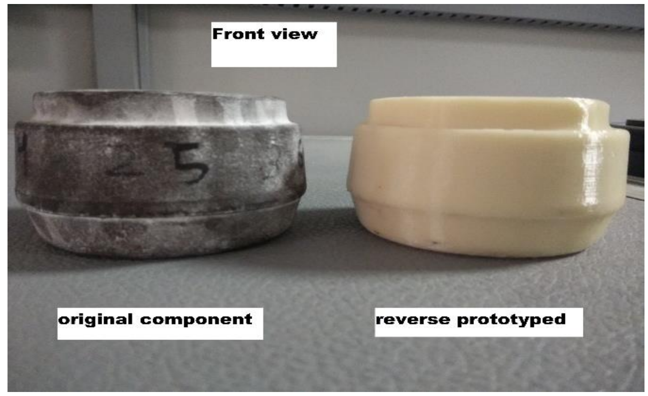
Structured light 3D scanning is not a fully mature technique and Currently, the accuracy of scanning is affected by the following: projector and detector lens aberrations, mechanical vibrations, calibration unit quality, stability of the ambient temperature and lighting during measurement and calibration, the surface properties of the object being measured (color, roughness, and reflectivity), and temperature. Accurate measurements was obtained under stable conditions only therefore proper sensor calibration is ensured. Illumination exhibits strong influence on the range accuracy of structured 3D light scanners therefore it is desirable to have light grey surface, since it is the least sensitive on ambient light and program settings hence solvent based developer is used on the surface to get best scanning results. Any deviation between the calibration temperature and the actual temperature will result in errors caused by the thermal expansion of the materials used for scanner construction and changes in electronic devices operating characteristics therefore both the component and the scanning equipment are kept in same environment and all the measurements are taken in optimum temperature range set while calibration.

4. CONCLUSION

In this research paper after optimizing scanner settings a coated forged end clamp of tractor is scanned. With this simple example a positive attempt has been made to make familiar with data acquisition stage and it is made clear what are various sources of scanned data errors, remedies and precautions needed to be taken to achieve better quality and the type of various inspection tests that can be performed to estimate the accuracy between actual and CAD file and further improvements can be done based upon the data collected as in this case all the root mean square values and median standard deviations values at each point is limited within a tolerance level of 0.020 mm on both sides or 20 microns is the desired achieved accuracy after optimization between original and reverse prototyped replica. That final CAD model finds wide applications in fields of die making and forging simulations which makes the production easier for this type of component.

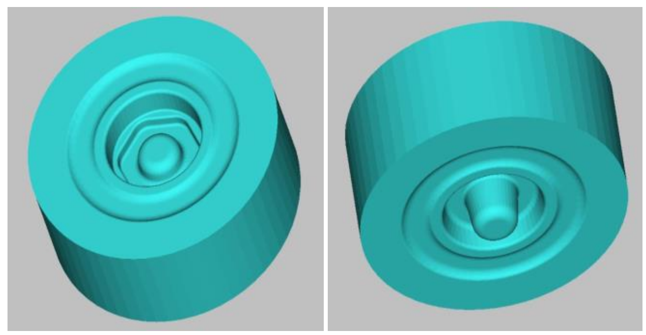


(a)

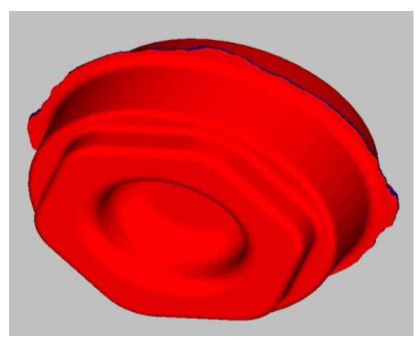


(b)

Figure 13 (a) front view (b) Top view of original component and reverse prototyped replica through RPT machine.



(a) (b)



(c)

Figure 14 bottom and top die pair for the prototype and forging flash generated with this die pair (a) Bottom die (b) top die (c) forging flash

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