Error analysis and point data processing of reconstructed surface by reverse engineering

R Ann Joachim Martin, J Daniel Glad Stephen, A Vinoth and E Muthu
Assistant Professor, Department of mechanical engineering, SRM Institute of Science and Technology, Kattankulathur, Chennai, India.
Email id - annjoacr@srmist.edu.in

Abstract. Reverse engineering is the processes of extracting design information (data points) from a product in an attempt to duplicate it. But when generating a surface using the acquired data points, there are a lot of surface inaccuracies compared to the original CAD model. The goal of this work is to reveal the errors between the shapes through a comparative study of the original CAD models and the generated surface models. To accomplish this task a mouse structure and an aerofoil are modelled in CAD Software and their NC codes are generated using master CAM. The models are then machined with these codes in CNC milling machine. Using portable CMM, laser scanning is performed on the fabricated models to collect the data points. With these data points the surface models are generated in GEOMAGIC and compared with the input models structured using CAD software. On comparison, it is inferred that the number of input data points of point cloud data significantly affects the surface accuracy of the reverse engineered model especially at the edges of the model. Experimental results on error analysis are reported which validates the above work.

1. Introduction
Reverse Engineering (RE) is described as the technique of acquiring an on-screen geometric 3D model of a prevailing part primarily depending on points recorded from the element floor with the aid of scanning it. Reverse Engineering technology isn't always to duplicate a current product but to collect a design idea from a current bodily version and generate a whole virtual product prototype and thereafter to enhance the product design. Reverse Engineering is accomplished via numerous levels like 3-D digitization (with 3D point cloud data), point cloud filtering (cleaning), alignment and surface reconstruction. Surface reconstruction is a critical step in reverse engineering to obtain the accurate shape of the item that is reversed. Lu et al. [1] defines reconstructing a surface as a technique of recovering the original surface from a few partial statistics including points, and portions of curves. Kumar et al. [2] describes the recognition of shape from the measured point data is called as reconstruction. Montegranario and Floater [3,4] describes reverse engineering as a way of converting a large number of data points got from the surface of an existing 3D part into an proper operational 3D model in computer, so that its volume shape and other features remains the same. Evolvement of virtual scanning gadgets at a reasonable market price has expanded the call for the vigorous rebuilding of precise models from factor cloud facts. So research on reverse engineering of 3D surfaces has become so important.

Raw information for surface reconstruction involves scanning the present element with laser line scanner in the shape of point cloud information [5–8]. A point cloud fact has a millions of coordinate
information points. Millions of coordinate information points slows down the floor reconstruction method [9, 10]. This may not be possible at all times because to be had algorithms have the functionality of handling a few million points, want further laptop reminiscence to run and store the concluding refashioned CAD model [11]. The portions of literatures describe reconstructing a surface as an ill-modelled trouble with a couple of solution and therefore the kind of factors affecting the surface reconstruction can be changed [12, 13]. Lim and Tan [14] describe sampling rate of a surface is crucial to the win of surface reconstruction process. Pardiñas et al. [15] used binning-type acceleration strategies in his algorithm to boost up the process of reconstructing a surface however it called in for the need to make a conciliation between estimate mistakes and computational pace by reducing the variety of developed points. Muller [16] designated that the noisy point cloud data is one of the most important factor that impacts the precision of the rebuilt surface. Yang et al. [17] also inferred that the noise of the input coordinate point influences the precision of the surface to be reconstructed. From all the above mentioned papers it is clear that there are a lot of surface inaccuracies compared to the original CAD model when generating a surface using the acquired data points. And so the study of these inaccuracies becomes vital.

2. Surface Reconstruction

2.1. Part Selection

This paper deals with two part models. One is the 3D model of a computer mouse which is considered because the model consists of B-spline curve and other one is an aerofoil (NACA 4415) as the surface represents a proper curve. Other reasons for considering these models is that both the models have a very smooth profile, which would enable to acquire good enough coordinate point cloud so that the mounting in the CMM will be easier.

2.2. Part Modeling

For the 3D part model of the mouse the dimensions taken are that of a real life product of a computer mouse. The generative shape design feature of CATIA is preferable as the surface that we need to generate with the available dimension can be done properly, the completed model of the mouse is shown in Figure 1. Also for the aerofoil design of NACA 4415 the coordinates available at www.airfoiltools.com were downloaded and the 3D model of the aerofoil was generated in CTIA, which is shown in Figure 2.

![Figure 1. CAD model of Mouse.](image1)

![Figure 2. CAD model of NACA 4115 aerofoil.](image2)
2.3. Generation of NC codes & Fabrication
Both the 3D models were imported into CAM software, and three separate NC codes were generated for both the part models separately, one for surface roughing, one for semi finishing and one for finishing. With the help of a 3-Axis Vertical Milling Centre (Jyoti PX10 VMC), the parts were fabricated. The fabricated parts are shown in Figure 3 and 4.

![Made-up model of Mouse.](image1)

![Made-up model of NACA 4115 aerofoil.](image2)

2.4. Laser scanning and post processing
With the help of FARO Fusion Arm with laser line probe and GEOMAGIC Design X software scanning of parts were possible and the feature of live scan was used to digitize both the parts by obtaining maximum possible coordinate points. After acquiring the coordinate point cloud, unwanted extra surface are selected and deleted. The obtained surface is a combination of multiple scan therefore merge tool in GEOMAGIC is used to obtain a single scan. Top and bottom scan is imported in GEOMAGIC software and align between scan data by local based on picked points is done. Appropriate points are chosen on both the scans and it is ensured that both the scans align properly with each other. After that is the important step, generation of surface. This step is crucial for reverse engineering as it is used to convert merged scan data into a surface. Auto surfacing, global re-mesh or rewrap can be used for surfacing and post this, a complete surface is obtained. The obtained model is given below in Figure 5.

![Figure 3. Made-up model of Mouse.](image3)

![Figure 4. Made-up model of NACA 4115 aerofoil.](image4)
3. Aligning of reconstructed and CAD models

Once the reconstruction of both the models are done, the original CAD models were imported in GEOMAGIC and alignment feature available in GEOMAGIC was used to align the rebuilt model and the model done using CAD to align with each other. Best fit a sub feature was used to fit the models done on scanning and using CAD. Developed model using CAD was the target body and scanned model was reference body. Post this an aligned model of CAD and scanned model was obtained for Mouse and Aerofoil, which are shown in the Figure 6 below.

![Figure 5. Scanned model of mouse and NACA 4115 aerofoil.](image)

![Figure 6. Alignment of CAD model with SCAN data.](image)

3.1. Comparison of CAD model and reconstructed model

Accuracy analyzer feature was used to compare the CAD model and the reconstructed models of the mouse as well as the aerofoil, the comparison between the models are shown in the Figure 7 & 8 below.

![Figure 7. Error analysis between CAD and Scanned model of Mouse.](image)
4. Conclusion
The 3D scanned data of the model were merged with CAD model to capture the deviation between the scanned model and the CAD model. The various factors contributing to the error are vibration of the scanning table, scanning technique, scanning probe settings and selection of inappropriate method for combining the scanned data. It was also noted that the sharp edges were difficult to scan and the error in sharp region were high compared to the other regions. The machining parameters also important to fabricate the component as per the CAD model. Any deviation in the machining also produces the error and that will be reflected in the scanned model. This study has identified the main contribution of error sources. Further studies are required to determine the optimum scanning technique and scanned data processing.

5. References
[1] Lu D, Zhao H, Jiang M, Zhou S and Zhou T 2015 A surface reconstruction method for highly noisy point clouds InInternational Workshop on Variational, Geometric, and Level Set Methods in Computer Vision Springer
[2] Kumar GS, Kalra PK and Dhande SG 2004 Curve and surface reconstruction from points: an approach based on self-organizing maps Applied Soft Computing 5 55-66
[3] H Montegranario and J Espinos 2007 A regularization approach for surface reconstruction from point clouds Appl. Math. Comput. 188 583–595
[4] M S Floater and K Hormann 2004 Surface parameterization: a tutorial and survey, Multiresolution in Geometric Modelling Springer
[5] D Levin 2004 Mesh-independent surface interpolation, in: Geometric Modeling for Scientific Visualization Springer-Verlag
[6] S Fleishman, D Cohen, M Alexa and C T Silva 2003 Progressive point set surfaces ACM Trans. Graphics 22 997–1011
[7] Amenta N and Kil YJ 2004 Defining point-set surfaces ACM Transactions on Graphics (TOG) 23 264–70
[8] Yau HT, Chen CY and Wilhelm RG 2000 Registration and integration of multiple laser scanned data for reverse engineering of complex 3D models International Journal of Production Research 38 269-85
[9] Song H and Feng HY 2008 A global clustering approach to point cloud simplification with a specified data reduction ratio Computer-Aided Design 40 281-92
[10] Johnston RA and Price NB Surface reconstruction of laser scanner data using piecewise RBF methods In2008 23rd International Conference Image and Vision Computing New Zealand IEEE
[11] Carr JC, Beatson RK, Cherrie JB, Mitchell TJ, Fright WR, McCallum BC and Evans TR 2001 Reconstruction and representation of 3D objects with radial basis functions InProceedings of the 28th annual conference on Computer graphics and interactive techniques
[12] Zhao HK, Osher S and Fedkiw R 2001 Fast surface reconstruction using the level set method InProceedings IEEE Workshop on Variational and Level Set Methods in Computer Vision
[13] Jalba AC and Roerdink JB 2009 Efficient surface reconstruction from noisy data using regularized membrane potentials *IEEE Transactions on Image Processing* **18** 1119-34

[14] Lim CW and Tan TS 2006 Surface reconstruction by layer peeling *The Visual Computer* **22** 593-603

[15] Roca-Pardiñas J, Lorenzo H, Arias P and Armesto J 2008 From laser point clouds to surfaces: Statistical nonparametric methods for three-dimensional reconstruction *Computer-Aided Design* **40** 646-52

[16] Muller H 1997 Surface reconstruction—an introduction *In* Scientific Visualization Conference *(dagstuhl’97)* *IEEE*

[17] Yang Z, Deng J and Chen F 2005 Fitting unorganized point clouds with active implicit B-spline curves *The Visual Computer* **21** 831-9