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Research Article

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Integrating Reverse Engineering with CNC Machining

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Abstract

Objects with complex geometric features find challenges in their computer-aided design (CAD) model creation and fabrication. Reverse engineering is a technology used to create the CAD model of the physical objects with complex geometry while CNC machining can be used to manufacture the object by giving proper cutter path. The aim of the paper is to integrate reverse engineering with CNC machining so that objects with complex geometry can be manufactured conveniently. An object (ultrasonic horn) having geometric features like planer surfaces, curved surfaces, slots etc. has been taken to demonstrate it. Further, deviation in the fabricated object from the original object has been computed and maximum deviation is found to be only 3%.

Keywords

Reverse engineering, Computer-aided design model, CNC Machining

Introduction

Reverse engineering is the technology of creating new products by making CAD models of the existing ones. The CAD model is used to analyze, interpret, and improve the current items which is further used in production and manufacturing [1]. It starts by scanning the component which gives the point clouds. These point clouds are used to follow the reverse engineering principles to create geometry. The process of modelling of the parts with complex geometry becomes easy with it [2]. With a few exceptions, the majority of procedures described in the literature follow a predetermined process. These include using a 3D scanner to scan the component, gathering data, processing the original data, segmenting point clouds and meshes, creating analytical surfaces, finishing operations (like joining adjacent surfaces) and reconstructing the CAD model [3].

Reverse Engineering when integrated with manufacturing processes like additive manufacturing or CNC machining is advantageous for producing parts with complex geometries with reduced lead time. So, studies have been done in this direction. Eslami et al. [1] scanned an object (aeroplane wing) using a laser scanner and the resulting point cloud data was processed using Geomagic reverse software to create its CAD model. This CAD model was transmitted to a 3D printer to fabricate it. Varim and Yumurtachi [3] scanned a damaged motor cam gear and transformed it into a mesh model. Further, a solid model was created, and 3D printer was used to create its prototype. Wu [4] used a vehicle safety hammer as an example to apply reverse engineering for modelling it. To finish the 3D modelling, the safety hammer was divided into three parts (handle, gauntlet, and head sections) based on the workpiece's surface properties. Further, they were combined using Boolean operations to produce a complete 3D model. PowerMILL software was used to generate the G codes for CNC machining. Riyadi et al. [5] created the CAD model of an impeller by using the scanned data. The CAD model was imported into a program called Geomagic Wrap to modify its shape. Further, Siemens NX software was used for machining simulation and then the machining was done. Point cloud of a worn-out crank shaft was obtained by Coordinate Measuring Machine (CMM) and imported to ProE software to create the CAD model. Yadav et al. [2] and Kansal et al. [6] discussed a systematic approach for CAD model generation of hole features from point cloud data. Liu [7] proposed an adaptive process for automatic reconstruction of CAD model from point clouds. Primitive shapes were extracted from point clouds by RANSAC algorithm, then it analyses deviations of points from the fitted primitive shapes by histograms. For point cloud patches segmented unreasonable, the approach updates parameters of segmentation according to the Gaussian noise and repeats the primitive shape detection process. Iterations were done to detect reasonable primitive shapes from point clouds. Then a rule for obtaining CAD models by primitive shape alignment was introduced. Muslimin et al. [8] worked for generating tool path directly from the point cloud. The tool path was converted into numerical control program by postprocessor which is an important medium between CAD/CAM system and machine tool. She et al. [9] studied to analyze the tool path file numerical control intermediate produced by the commercial software Mastercam to develop the postprocessor for five-axis machine tool. Barai et al. [10] presented an approach for reverse engineering technique using CMM and a design software CREO. Gonzalez et al. [11] studied to design an integrated curricular training program in computer aided tools for the design and manufacture of mechanical components based on reverse engineering techniques. Marzoog et al. [12] used reverse engineering approach to create a 3D CAD model for power stern. NURBS curves were used to formalize the edges of segments, then tabulated surfaces according to the segment geometry were fitted. Shabani and Dukovski [13] redesigned a mechanical part with simple geometry by reverse engineering and topology optimization. The redesigned part was further manufactured using additive manufacturing. Lopez and Vila [14] prepared a surface model by using wireframe geometry to be 3D printed.

The above study shows the various works for the integration of reverse engineering with manufacturing processes. However, some of them have limited up to primitive shapes [7], simple geometry [13], and tabulated cylinder [12]. Many of the studies have been done for integration with additive manufacturing [1, 3, 11, 13, 14] which has limitations as, the materials to be processed, quality of the fabricated part and post processing required after fabrication. So, in the present work an effort has been made to integrate the CNC machining with reverse engineering. Initially reverse engineering is applied to create a CAD model of an existing object which is further manufactured by CNC machining. Geometrical features of the object used in the work includes plane and curved surfaces with slots. SOLUTIONIX C500 3D laser scanner was used to scan the object and processed data in STL file format was imported to NX software. Planar and curved regions in it were formed by NURBS (Non-uniform rational B-splines) surfaces and slots were created by using feature curves. The obtained CAD model was used further for simulation of CNC machining and the generated tool path were converted into G-codes and M-codes for the fabrication of the part by VMC (Vertical Milling Centre) CNC machine. Finally, deviation between the original part and fabricated part was computed.

Various products like prosthetics, body parts of automobiles and aircraft consist of complicated geometric features which need to be initially modelled and then fabricated by CNC machining. It is hoped that the present work will be helpful in it.

Methods

The process of reverse engineering is applied to create the CAD model of an object (ultrasonic horn) which is further used for CNC machining. It starts by scanning the object. The obtained data during scanning is used for CAD model creation. Geometric features of the object are given in the following section which are considered during CAD model creation.

Geometric features of the object

Figure 1 shows the ultrasonic horn. As mentioned earlier geometric features like plane and curved surfaces with slots can be seen in it. Further, joining of the curved surface with planer surfaces at the two ends can be seen in two different ways. At one end a sharp edge can be seen which shows C^0 continuity (Point Continuity) while at the other end curved surface is blending with planer surface tangentially which shows C^1 continuity (Tangent Continuity). The CAD model of this object was created by initially scanning it with SOLUTIONIX C500 3D laser scanner (Figure 2) and the data obtained in it was processed as explained in the following sections.

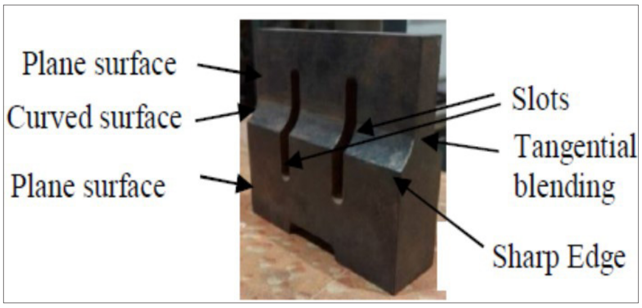


Figure 1: Ultrasonic horn.

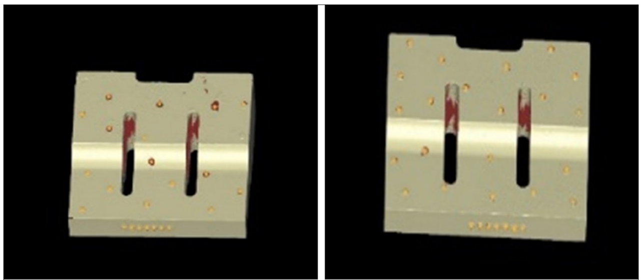
Figure 2: SOLUTIONIX C500 laser scanner.

Scanning and data processing

The object was prepared for scanning by cleaning its surface. Then 3D scanning spray was applied on the object's surface to avoid reflection and a few points were marked with marker as scanning was done in more than one view. Further SOLUTIONIX C500 3D laser scanner (Figure 2) was used for scanning. This scanner is suitable for small and medium-sized objects. It utilizes Blue light technology and is compatible with EzScan software.

Scanning of the whole object was done by taking two views of the object. The two views after scanning are shown in figure 3a and 3b. The data points belonging to these views were in their own local coordinate system. However, for further processing, they required to be merged. It was done by aligning the data points from two views with the help of marked points. Figure 4 shows the view after merging them.

File obtained by the scanning process was in STL format and was further processed to get a neat and clean mesh model like unnecessary data points carried by them were selected and removed, noise in the data were corrected, missing mesh area, and open meshes were discovered to repair them. Further, the surface in the curved region and the slot needed to be more precise. So, the triangle edge length in this region was reduced.



(a) View 1 **(b)** View 2

Figure 3: Scanned views of the object.

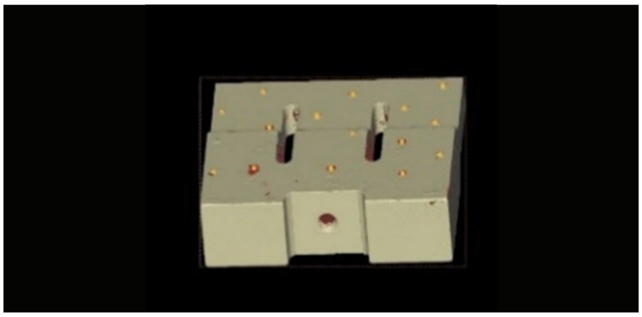


Figure 4: Merged view.

3D CAD model creation

CAD model in the present work is generated using NX software. The mesh model in the STL file format, as obtained in previous section is imported to NX software. The mesh model consists of triangular facets which need to be replaced by smooth surfaces for CAD model generation. Various patches of point cloud were considered such that a smooth surface on each of them may be fitted. NURBS surfaces were used to fit over them sequentially. Further, joints of these surfaces were smoothed by using parametric blending surfaces [15]. Finally, slots were created by drawing feature curves [16] in the CAD model. The feature curves with the slots are shown in figure 5. The final CAD model created using this procedure is shown in figure 6. Figure 6 shows a smooth CAD model, however with sharp edges at the appropriate places as they were in the original object. Deviation between the mesh model obtained previously and the CAD model prepared in this way is also discussed in the section of results and discussion.

CNC machining

CAD model created as explained in previous section is further used for simulation of CNC machining and G-code, M-code generation. For the final product to be produced stock was decided to be in the form of rectangular block with size of 158 x 135.2 x 44 mm. This size of the stock was decided after considering the size of final product and machining allowances. Machining was decided to be done in two steps: roughing and finishing. For rough machining face milling cutter with diameter 50 mm and for finishing work ball nose end mill with 10 mm diameter were taken. Machining parameters were decided by optimum load on tool, which was done by considering adaptive clearing method in the software. It ensures maximum tool load during all phases of machining cycles and allows deep cuts without the fear of breaking the cutter. Further, tool safety was ensured by defining planes for bottom height (BH), top height (TH), clearance height (CH) and retract height (RH) (Figure 7). Different movements of tool were bounded within these planes only.

After setting all the parameters as described above toolpaths were generated by simulation for rough and finish ma-

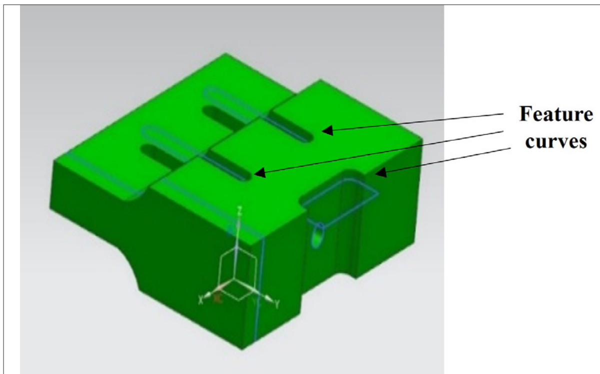


Figure 5: Feature curves with slots.

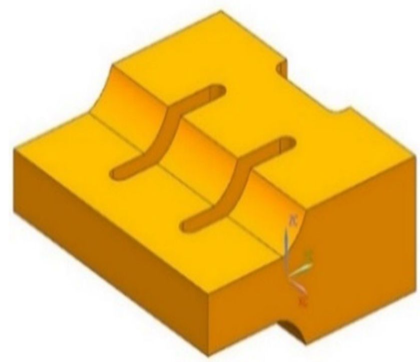


Figure 6: Final CAD model.

chining. Yellow curves in figure 8 show the tool paths for rough machining and blue curves show the tool paths for finish machining. Simulation also ensured to produce a flawless machining process.

G-codes and M-codes required for CNC machining (HMT VMC in the present work) were produced by postprocessor from the generated tool paths. HMT VMC is a 3-axis vertical milling machine with an axis travel range of 200 mm in longitudinal direction, 125 mm in cross direction and 200 mm in vertical direction. It can carry job weights up to 20 kg and uses a MACH3 controller.

The machining process was initiated by clamping the stock on the bed of VMC milling machine (Figure 9). Machining codes (G-codes and M-codes) generated were imported to the controller of the machine. The machine coordinate system was matched with the program coordinate system by initially setting origin at the corner of the stock. Finally, the machining was done as mentioned before in two steps. Initially by roughing operation as shown in figure 9 with face mill cutter. The block produced after roughing operation is shown in figure 10. Further, smooth surfaces were produced by finishing operation with ball nose end mill cutter as shown in figure 11. After completing machining on one side the object was unclamped and mounted on the machine from the other side. The object was machined in the same manner from the other side, as it is symmetrical from both the sides (top and bottom). Finally, the slots were cut using an end milling cutter and the part was produced as shown in figure 12.

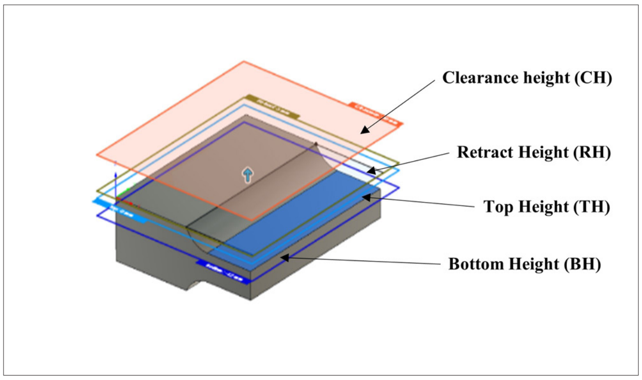


Figure 7: Planes for tool safety.

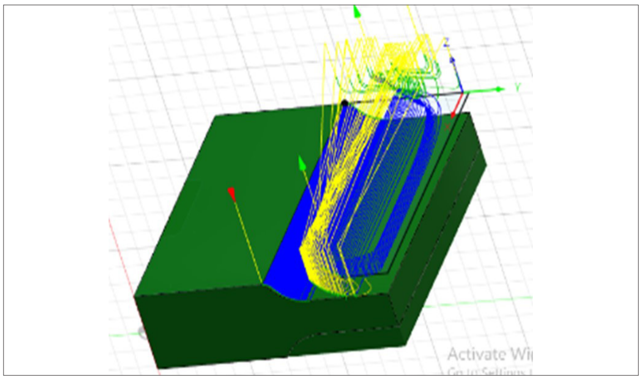


Figure 8: Tool path for rough and finish machining.

Figure 9: Stock mounted on the machine bed.

Figure 10: Machined block after roughing operation.

Results and Discussion

In the present work, as described in previous section reverse engineering is used to create the CAD model of an object (ultrasonic horn). It is initiated by scanning the object by a 3D laser scanner and the data obtained was transformed into a mesh (Figure 4). Further, smooth surfaces were fitted on various regions (planer as well as curved) of mesh model to create a smooth CAD model. Slots on the model were formed by drawing feature curves (Figure 5) and final CAD model of the object was produced (Figure 6). In this process mesh model was created by joining the scanned data points with straight lines while CAD model was created by fitting NURBS surfaces. These surfaces were fitted by approximating the data points. So, in the present work deviation between the mesh model and CAD model was evaluated. Figure 13 shows the deviation computed for it. Majority of the portion in figure 13 is seen in green colour which reflects the deviation within ±0.1 mm. Very little region is seen in yellow colour which is for the deviation between 0.1 - 0.4 mm. Different shades of blue colour can be seen in the curved region. From the observation, it can be said that the maximum deviation may be around -1 mm in the curved region. Further, colour of the boundaries of the slots are seen in the same shade as that of the other nearby regions. It shows that deviations between the mesh model and the CAD model are not markable due to slots.

Further, deviations between the original object and the object fabricated utilizing the procedure in this work were computed. Parameters used for computing the deviations are shown in figure 14. Measurements of the original object and

Figure 11: Finishing using ball nose end mill cutter.

Figure 12: Part produced after machining.

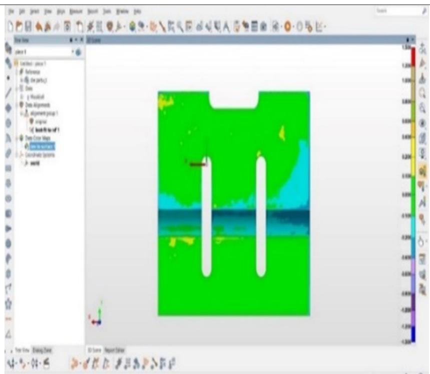


Figure 13: Deviations in CAD model.

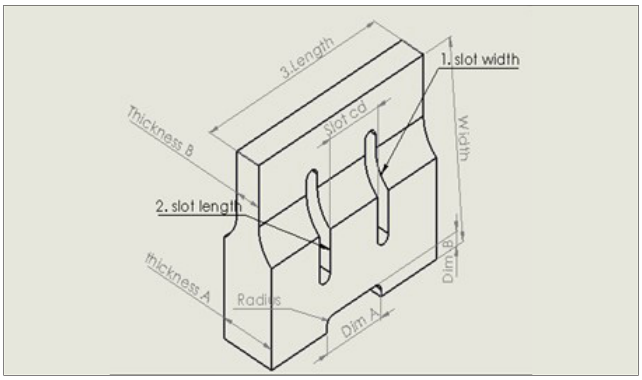


Figure 14: Fabricated object's measured parameters.

fabricated object were done with a vernier caliper of 0.01 mm resolution. Measured values with the deviations are given in table 1. Table 1 shows that the maximum deviation observed is 3%. Using the data of table 1 average accuracy is found to be 97.98%.

Table 1: Measurements with deviations.

Parameters as per Figure 14	Measurements of original object	Measurements of fabricated object	Deviation (%)
Length	153.0	155.0	1.31
Width	135.0	136.5	1.11
Thickness A	44.0	44.5	1.13
Thickness B	20.0	20.6	3
Dim A	50.0	51.5	3
Dim B	10.0	10.2	2
Slot Length	72.0	75	2.78
Slot Width	10.0	10.1	1
Slot CD	54.0	55.5	2.78

Conclusions

The present work deals with the integration of reverse engineering with CNC machining so that parts with complex geometry can be manufactured. Ultrasonic horns having various geometric features have been taken to demonstrate it. The following conclusions are drawn.

- NURBS surfaces were used to fit the scanned data over planar as well as curved regions with proper continuity at the joints. This shows that any type of surface (freeform or regular) can be formed by following this process.
- Slots in the CAD model were formed by drawing feature curves which gives the way to make slots of any shape in a very simple way.
- The fabricated part was compared with the original part to compute the average accuracy and maximum deviation which are found to be 97.98% and 3%, respectively. It shows that the part fabricated by following the process explained in the present work is very close to the original part.
- The success of the presented work shows that it can be applied to fabricate the parts with complicated geometries like in manufacturing the prosthetics for dental applications, limbs etc. and various engineering products considering aerodynamic properties like aircraft or automobile body parts and many more. All these applications are having freeform surface construction and difficult to be made in conventional way.

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Conflict of Interest

None.

Credit Author Statement

Md. Ehtesham: Methodology, Investigation, Data analysis; Vandana Agrawal: Supervision, Writing - original draft preparation, Writing - review and editing. All the authors read and approved the manuscript.

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