# REVERSE ENGINEERING APPROACH FOR RAPID MANUFACTURING OF FREEFORM COMPONENTS

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**ABSTRACT**

*Reverse engineering is a process of obtaining a geometric computer aided design (CAD) model from three dimensional (3D) point clouddata acquired by scanning/digitising existing parts. There are several reasons for using reverse engineering (RE) technique; absence of the 3D CAD model of the part is one of the key reasons. Companies are investing in RE to reduce the time to create a prototype and to shorten the time to market for a product and to have an edge over their competitors. In the present study, we reverse engineered a specimen component with freeform surfaces via additive manufacturing technique. For this purpose, we used a contact type 3-axis point to point coordinate measuring machine (CMM)to obtain a point cloud data of the component. The CMM works on Geo-met software which can export measured point cloud data in IGES format that a CAD system can read. The CATIA V5 solid modelling software is used to convert point cloud data into 3D CAD model by creating a surface onto the point cloud and then it was savedas an STL file. Once we have an STL file with us, we can fabricate a physical part using either subtractive or additive manufacturing. We fabricated a physical part using selective laser sintering (SLS), an additive manufacturing machine as well as a computer numeric control (CNC) milling trainer XLMILL.We have obtained satisfactory results in both the cases; however time taken and difficulty faced to manufacture the component were less in case of additive manufacturing.*

*Keywords: Reverse Engineering, Coordinate Measuring Machine, Additive Manufacturing, Computer Aided Design, Computer Numeric Control (CNC)*

## I. INTRODUCTION

Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/digitizing existing parts/products. The process of digitally capturing the physical entities of a component, referred to as reverse engineering, creating a computer model and then it to manufacture the component. The accuracy and correctness of the data significantly affect the quality of final CAD model as well as the machined work piece.
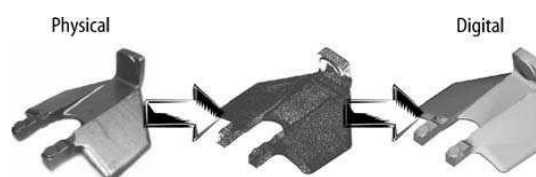


**Fig. 1: Physical to Digital Process [1]**

## 1.1 Reverse Engineering Process

RE is a three phase process which consists of Part digitization, Point processing and CAD modelling. Digitization is employed to scan the part geometry, producing point cloud data which define the surface geometry. Digitization is accomplished by variety of contact and non contact digitizers. Point processing involves importing the point cloud data; reduce the noise in the data collected.
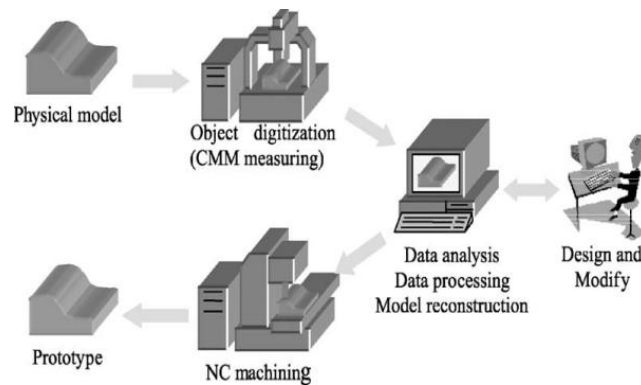


Fig. 2: RE process [2]

CAD modelling is required surface fitting algorithms to generate surfaces that accurately represent the 3-dimensional information described within the point cloud data sets.

## 1.2 Digitization

The first step in creating a CAD model for an existing part is part digitization. Digitization is process of acquiring point coordinates from part surfaces. The result of the digitization process is a cloud of 2-D or 3-D data points stored as an image. Light intensity (visual images), nuclear magnetic images commonly known as magnetic resonance images (MRI), and thermal image are several types of 2-D images. Light intensity images (LI), which represent the variation of the light intensity over a scene, are the most common 2-D images. Vision systems are used to acquire intensity images. A 3-D image, which is normally called a range image (RI), is a map of depth information at different points on a scene. Range image data can be acquired using one of the available contact or non-contact techniques.

## 1.3 CAD Modeling

To model the part surface in CAD we need to identify surface features from the cloud of points acquired by digitization. These features include boundaries and surface segments. The output of the surface segmentation process consists of labelled points belonging to a particular region. Part modelling is accomplished by fitting variety of surfaces to the segmented data points. Various types of surfaces are used to model the segmented data in CAD. Polynomial functions are used to model standard engineering surfaces such as cylindrical, conical etc. Free form surfaces are modelled using parametric surfaces such as B-Splines, and Bezier surfaces. The output of this phase is geometric model in one of the proprietary formats such as IGES, VDA, STL, DXF, OBJ, VRML, ISO G Code, etc.

## 1.4 Applications

Reverse engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewellery design and reproduction For example, when a new car is launched on the market, competing manufacturers may buy one and disassemble it to learn how it was built and how it works. In software engineering, good source code is often a variation of other good source code. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly.

## 1.5 Reverse Engineering Software

There is no single RE software that can completely satisfy the requirements of RE data processing and geometric modelling. Based on applications, RE software can be classified into the following groups: Hardware control, CAD entity manipulation, polygon manipulation, polygon and NURBS surface construction, 2-D scan image processing and 3-D modelling, 3-D inspection, and NURBS surface and solid modelling.

### Table 1: RE Software [1]

| S.No | Application | Main Functions | Software |
|---|---|---|---|
| 1 | Hardware control | Control RE hardware for data acquisition. Normally, basic data processing operations and data conversion are also provided. | Geomet, Mitutoyo Cosmos, Metris Scan |
| 2 | CAD entity manipulation | Manipulate CAD entities that are extracted from point clouds and polygon meshes. CAD entities include points, contour lines, and CAD primitives such as circles, rectangles, cylinders, and boxes. | Imageware and other common CAD packages such as Catia UG, Pro Engineer and Solid works. |
| 3 | Polygon manipulation | 3-D polygon data editing, modification, and optimization. | Catia Shape Sculptor and Viscam RP, Magics RP. |
| 4 | Polygon and NURBS surface construction | Provide a complete set of RE data processing tools from working with point clouds and polygons to constructing NURBS surfaces as well as 3-D inspection. | GSI Studio, Copy CAD, Rapidform, Geomagics, Polyworks (Modeler) and Paraform. |
| 5 | 2-D Scan Image Processing and 3-D modelling | Used for processing 2-D scan images (CT/MRI) and 3-D reconstruction. | Mimics, Rapidform, BioBuild, Velocity2, Amira, Scan IP |
| 6 | 3-D Inspection | Used for 3-D inspection, error map creation and analysis, inspection report and documentation | Metris Focus Inspection, Power inspect, Polyworks Inspector and Geomagic Qualify. |

| 7 | NURBS surface and solid modelling | Provide NURBS modelling and editing tools based on basic CAD entities and primitives. | Catia, Pro Engineers, UG, Solid works, and Rhino. |
|---|---|---|---|

In this paper, we have used a contact type 3 axis point to point CMM for reverse engineering of mechanical component having free form surface. First of all, point cloud data were obtained using contact probe. The CMM work on Geomet software, it offer feature data point scanning and exporting measured features and data clouds as IGES entities that the CAD system could read. The CAD system will then analyse the information and form the solid objects or motion paths for CNC tools.

The CATIA V-5 solid modelling software is used to convert point cloud data into solid model and then to STL file. If the part is to manufacture by AM approach, we require a STL part file of the component. If it is to be manufactured using CNC machine then either we can feed 3D part model directly to the machine or can generate part program using any CAM software like EdgeCAM. We have generated a part program using EdgeCAM software. We have obtained satisfactory results in simulation of the program on CNC trainer "XLMILL" available in our CIM lab.

## II. LITERATURE REVIEW

This literatures survey for selecting the objective of our work and applied the methodology, algorithms, and techniques for any existing product that can be easily re-engineered with less cost of production and shorten lead time.Chen et al. [15] presented a case study on reverse engineering of turbine blades used in nuclear power generators. They was developed reverse engineering approach, the modified adaptive model based digitizing process to the three dimensional geometric design of turbine blades. Eyup Bagci [3], Using this approach, accurate CAD models can be efficiently generated and the product design cycle of turbine blades can be successfully linked.The researcher take three different samples cam, turbine blade and Ataturk bust have been broken or worn, could be reproduce with obtained CAD data. Damage or broken parts are generally too expensive to replace and today industries demanded short lead time to satisfy this need. These problems have been solved by reverse engineering techniques and referring to some practical approaches; establishing continuity across curve and surface patches is an important concept in the free form surface modelling. The CAD models were recovered to consider parametric and geometric continuity. The iso-photon method was used for surface continuity analysis. As a result application of RE approach to gaining speed the product realization process is currently gaining momentum and largely decreases manufacturing cost.

Nagy and Matyasi [16], after an analysis of STL file the researcher present a method to detect defects in the surface representation and to analyse the shape of the approximated surface by constructing a polyhedral data structure from the STL file. In this paper different triangle meshes representations is applied and using all the mathematical tools of geometric modelling for model reconstruction, also the construction of an edge-oriented data structure from a triangle mesh. This data structure includes numerical data and a full topological description of the meshed model. It is suitable for the solution of the problems emerging in rapid prototyping and for shape analysis. Manzoor Hussain [4], apply the reverse teginering technique for copying the product from an existing object. The object are reversed in this case study is injection mould part with two damaged cavities in the part. Duplicating the object with the help of CMM and CAD/CAM software like Pro-Engineer, Mastercam etc. are

used in this case study. CMM is used to digitize the part, taking coordinates of the various points on the surface of the object and converting it into IGES file and using the same file in the CAD/CAM software with required interfacing creates a surface or solid model of an object. Finally this solid model is used to generate CNC part program to manufacture the part on CNC Machining centre. For the purpose of duplication it check the accuracy and error analysis of a part then found that scanning along and across directions in surface will improve the accuracy of surfaces, and also depend on the complexity of shape. If scanning data is converted into datum curve, 50% of manual work can be reduced because lot of time can spend to load the file on CAD software and convert into curves. M. Salman [5], present an investigation of reverse engineering technique to generate free form surface in computer aided design system from physical objects. The technique used in investigation are data acquisition, registration, data pre-processing, polygon mesh, segmentation, surface fitting, and surface model generation. The output from polygon meshes i.e. data in STL file format can be for rapid prototyping which leads to rapid product development. Applying these techniques lead to reduction of product design times, easiness of product design modifications and rapid product development.

## III. SOLID MODEL GENERATION USING CATIA V5

Fig. 3 showing the work piece to be reverse engineered. The dimensions of the work piece are as follows: length - 80 mm, width - 50 mm, maximum height - 20 mm. This workpiece is fixed on the table of the CMM shown in Fig. 4. The point data on the surface of the work piece were taken using contact type probe. The point cloud data is shown in the Fig. 5.



**Fig. 3: Wooden Work Piece with**

**Free Form  Surface**



**Fig. 4: Phoenix 3-axis CMM**

Following steps are required to convert point cloud data into 3D CAD model:

    a)  Import the point cloud data

    b)  Join the coordinates

    c)  Define the plane according to the profile

    d)  Close the volume

    e)  Select the command extrude, sweep, trim for surface modelling

    f)  Then all the surfaces of part are converted into solid Model by part design
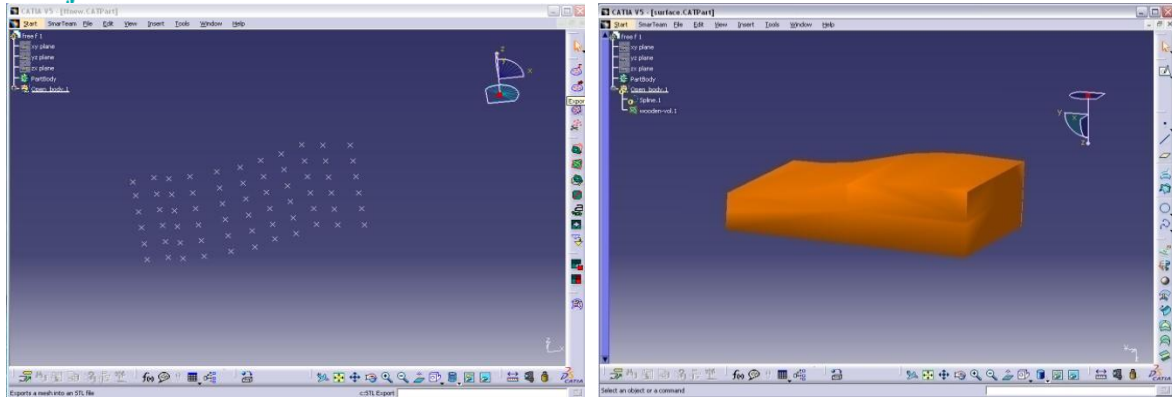
**Fig. 5: Point cloud data imported in CATIA V5**



**Fig. 7: Solid model obtained in CATIA V5**
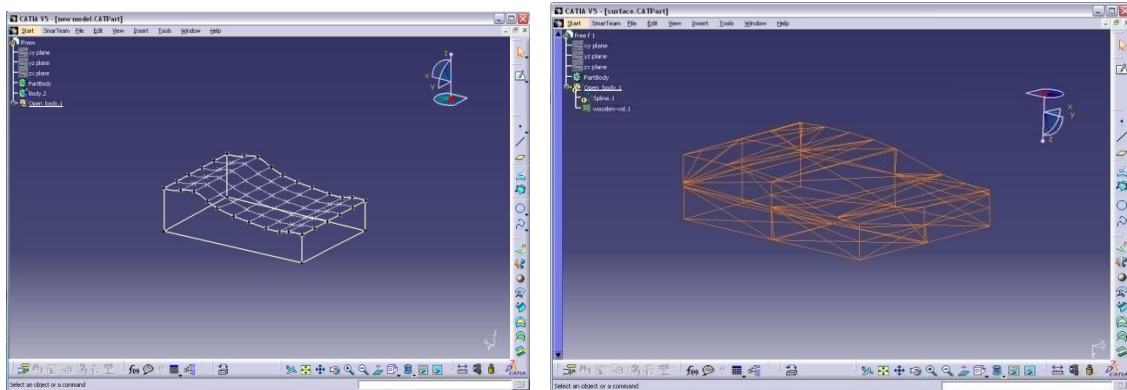


**Fig. 6: Joining coordinates, defining planes and closing of the volume**



**Fig. 8: STL file generation by CATIA V5**

With the help of CATIA V5 software the solid model is converted into STL file contain triangular facet representation of surfaces and have become standard data inputs of rapid prototyping and manufacturing system. This STL file can be utilized as standard input in additive manufacturing technology or importing in Edge cam software for G- code generation.

## IV. RESULT AND DISCUSSION

In this study, we have utilized the reverse engineering technique on physical part of free form surface by coordinate measuring machine, is a contact type 3-axis point to point scanning, work on Geomet software. Geomet offers feature data point scanning and exporting measured features and data clouds as IGES entities that the CAD system could read. The CAD system (CATIA) will then analyse the information and form the solid objects and then the part is manufactured by SLS machine and CNC trainer XLMILL.

The CAD software also generate STL file from solid model, further this STL file of a component is used to manufacture by additive manufacturing approach, or generate NC code for CNC Milling. For fast product development of RE cycle, it is not necessary to construct CAD model. This will be described by various algorithms for constructing STL file directly from digitized data.

The Experiment has done on Phoenix 112 point to point Coordinate Measuring Machine (CMM) have measuring range x = 300 mm, y = 300 mm, z = 250 mm with 3 mm ball bar diameter working on geomet software. In scanning utilize manual scanning technique of free- form surface and getting point cloud data coordinates of free form surface in x, y, z direction. Export the data by geomet software into three formats are
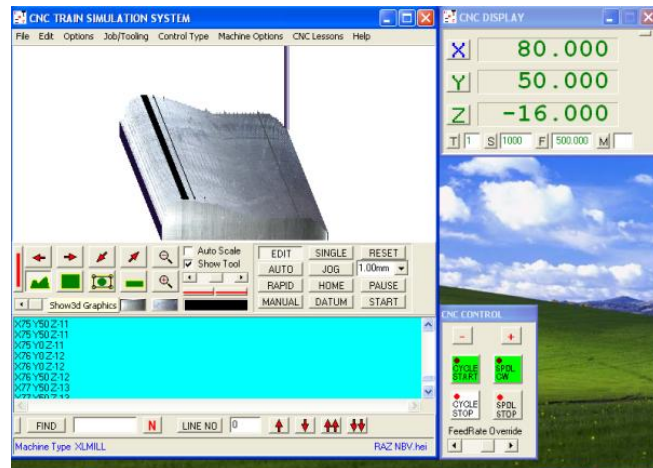
ASCII (American standard code for information interchange), IGES (Initial Graphics Exchange Specification), and DXF (Design Axis Format) that the CAD system could read.

The CAD software, CATIA V5 is used to import the data that are available in various formats. After importing the point cloud data in CATIA V5, it converts the point cloud data into curves and then it to surface generation. Finally the surface of the part is converted into solid 3D model. Then the part is manufacture by XL Mill.



**Fig. 9: CNC XLMILL Trainer**                    **Fig. 10: Isometric View of job**

After scanning the component by CMM, get the coordinates of surface in x, y, z direction that are used to generate the G-Code for manufacturing the component in XL Mill.The physical part of free form surface has successfully created through reverse engineering technique by generating program for toll path motion in XL Mill. Some vendors offer software that will generate CNC tool path data directly from a point cloud or polygon mesh.

Most additive manufacturing machines accept an STL file format or a similar triangulated format. In this study we have created a solid CAD model from the point cloud data by fitting a surface over the data. Alternately an STL file can directly be obtained by using a piece of programming codes. Almost all the CAD modellers now offer STL file generation from the CAD model, so there is another route to rapid prototyping.

We have used EOSINT P395 SLS additive manufacturing machine to fabricate the part. The powder material used to fabricate the part is polyamide (PA 2200). The STL file was first loaded into Magics RP to check and repair any error in the file such as inverted triangles etc. Now, the part is loaded into EOSINT P395 machine. The image of the part fabricated on EOSINT P395 is shown in Fig. 11.

**Fig. 11: Image of the Part Fabricated on EOSINT P395 Machine**

## V. CONCLUSIONS

The work presented in this paper is focused on creation of CAD model and subsequently fabrication of a physical component with freeform surface by reverse engineering methodology. The point cloud data for freeform object is successfully obtained by contact type probe of a CMM. If the probe tip is too big i.e. larger than the radius of curvature of a feature on the part to measure, the result will be inaccurate. CMM manufacturers provide a compensation mode to correct for the probe geometry. For measurement procedure it is necessary to understand how the CMM proceeds to obtain the data point cloud. The Geomet software scans the part through a point grid and results in a regular point data distribution by automatic scanning. The number of points for each line is constant. The main problem is to define the best measurement procedure to capture all the details without unduly increasing the scan time.

The part is fabricated using subtractive as well as additive manufacturing techniques. Both the techniques were reasonably efficient in generating freeform surfaces. However, additive manufacturing seems to have an edge over subtractive processes because of the inherent capabilities such as no need for tooling, no geometrical restrictions etc. It is observed during the study that, in case of complex and freeformobjects additive manufacturing may prove to be faster, accurate and easy method in comparison with its conventional counterparts.

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