Vidya Jyothi Institute of Technology
(Autonomous)

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(Aziz Nagar, C.B.Post, Hyderabad -500075)

Department of Mechanical Engineering

Circular

MED/Major Projects/01 **Dt: 17.12.2018**

All the final year mechanical engineering students are informed that a project work has to be undertaken as a partial fulfillment for the award of degree. In this connection you are required to form into groups with three to four members. Grouping is done voluntarily by yourself considering the domain of interest in mechanical engineering. Hence you are required to submit the group along with the domain/project topic so that faculty member can be allocated as supervisor/guide. Also you can speak to the faculty member in choosing them as supervisors for the project work undertaken. The submission of the group to **Mr.Naveen Kumar**, Asst.Professor, who is project coordinator on or before **24.12.2018.**

HoD

(Dr.G.Sreeram Reddy)

18	ANANTH	15911A03A5	Study of composite materials-cotton fiber with silver nanoparticles and silver - aluminium	Mr.N.Praveen	VJIT	PO1,PO2,PO3,PO4,PO9,PO12, PSO1
	NIKHIL	94				
	PAVAN	61				
	SUNIL	A4				
19	AHMED MIR KHAN	15911A0355	Synthesis of magnetic nano particles (Fe_2O_3 & Fe_3O_4) using ARC discharge method	Mr.Abul Hasan	VJIT	PO1,PO2,PO3,PO4,PO9,PO12, PSO1
	GAURAV	71				
	UMAIR	90				
	MUSAB MOHAMMED	92				
20	SHASHANK	15911A03A1	Impact of post weld heat treatment on super duplex stainless steel welded joints	Mr.K.Srinivas Rao	VJIT	PO1,PO2,PO3,PO4,PO9,PO12, PSO1
	LOKESH	82				
	CHANDRASEKHAR	A2				
	AKHIL	66				
21	SATHISH	15911A0391	Friction stir welding by cimilar and disimilar metals	Mr.P.Sampath Kumar	Shanthi Industries Hyderabad	PO1,PO2,PO3,PO4,PO5,PO9,PO12, PSO1
	VAMSHI GOUD	75				
	SUMANTH	81				
	ASIF	88				
22	VAMSHI	15911A0370	Failure analysis of alloy wheel with reverse engineering approach	Dr.G.Sreeram Reddy	VJIT	PO1,PO2,PO3,PO4,PO5,PO9,PO12, PSO2
	HEMANTH	67				
	FAISAL	69				
	SOHAIL	89				
23	SAI KIRAN	15911A0373	Evaluation of mechanical properties of natural fiber reinforced composites with filler	Mr.J.Pradeep Kumar	VJIT	PO1,PO2,PO3,PO4,PO5,PO9,PO12, PSO1
	VENKAT RAM REDDY	80				
	AKHILESHWAR	57				
	NAGARJUNA	96				
24	RAHUL	15911A03A0	Investigation and performance characteristics of an internal combustion engine using alternate fuels	Mr.Shaik Ismail	VJIT	PO1,PO2,PO3,PO4,PO9,PO12, PSO1
	VINAY KUMAR	77				
	ROSHITH	86				
	VISHAL	58				
25	RAVI CHANDRA	15911A03A3	Restoration of damaged component using reverse engineering and rapid prototyping	Dr.G.Sreeram Reddy	Think 3D Hyderabad	PO1,PO2,PO3,PO4,PO9,PO12, PSO2
	VARUN TEJ	72				
	KARTHIK	64				
	JAINIL	74				

RUBRICS FOR EVALUATION OF PROJECTS

Criterion for Evaluation/ Rubric	Poor (1)	Satisfactory (2)	Good (3)	Very Good (4)	Excellent (5)
Requirements	Project does not adhere to its requirements.	Project minimally adheres to its requirements.	Project mostly adheres to its requirements	Project completely adheres to its requirements	Project completely adheres to its requirements and suits current day's industry needs.
Creativity	Project is significantly incomplete and lacking creativity.	Project is somewhat incomplete and slightly creative.	Project is complete and creative.	Project is complete, creative and novel.	Project is highly creative and visibly appealing.
Model Building	Contains no involvement of mechanical engineering concepts.	Contains minimal involvement of mechanical engineering concepts.	Contains involvement of mechanical engineering concepts in study-oriented approach.	Contains involvement of mechanical engineering concepts like design, fabrication, analysis etc. without any live model or simulation.	Contains involvement of mechanical engineering concepts like design, fabrication, analysis etc and working model/ simulation as well.
Quality of the work	Project is of poor quality work.	Project appears hastily created or is of poor quality work.	Project construction could benefit from more than a minimal amount of effort.	Project construction could be improved somewhat in select areas.	Project is of excellent, durable construction.

56	16915A0307	BOMMENA VENKATARAMANA	Experimental analysis of thermo electric refrigeration system using water as a refrigerant	14	14	18	46
57	16915A0309	DUNDHIGALLA SAI RAJ	Designing of automobile parts by using composite materials	14	14	18	46
58	16915A0311	G PRAVEEN	Designing of automobile parts by using composite materials	14	14	18	46
59	16915A0312	G USHA KIRAN	Designing of automobile parts by using composite materials	14	14	18	46
60	15911A0355	AHMED MIR KHAN	Study of magnatic nano material by arc discharge method	14	14	19	47
61	15911A0356	ANABATHULA GOWTHAMKRISHNA	Design manufacturing nad cost analysis of wall mounted bicycle stand	14	15	19	48
62	15911A0357	ARDHA AKHILESHWAR REDDY	Evaluation of mechanical properties of jute polyester composites	13	14	18	45
63	15911A0358	ATNURKAR VISHAL	Performance of emission chracteristics of IC engine using alterante fuel	13	14	18	45
64	15911A0359	BANOTHU NIKHIL NAYAK	Design manufacturing nad cost analysis of wall mounted bicycle stand	14	14	19	47
65	15911A0360	BEJJANKI NAVEENKUMAR	Design manufacturing nad cost analysis of wall mounted bicycle stand	14	14	19	47
66	15911A0361	BIKKASANI PAVAN KUMAR	Study of composite materials - cotton impregnation with Ag-Nano particles	13	14	18	45
67	15911A0362	BOMPELLY SAI KIRAN	Residual stress analysis of super duplex stainless steel welded joints using XRD	13	14	18	45
68	15911A0364	C KARTHIK	Restoration of damaged component using reverse engineering and rapid prototyping	15	14	19	48
69	15911A0366	CHIGURUKOTA SAI AKHIL	Impact of post weld heat treatment on the mechanical properties of super duplex stainless steel	14	14	19	47
70	15911A0367	CHINTAPALLY HEMANTH REDDY	Failure analysis of alloy wheel with reverse engineering approach	14	15	19	48
71	15911A0368	DAIDA MANOJ KUMAR	Performance and emission characteristic of dual fuel diesel engine with cotton seed oil and CNG	14	14	19	47
72	15911A0369	FAISAL MEHRAJ	Failure analysis of alloy wheel with reverse engineering approach	14	15	19	48
73	15911A0370	GADI VAMSHI KRISHNA	Failure analysis of alloy wheel with reverse engineering approach	14	15	19	48
74	15911A0371	GAURAV JAIN	Study of magnatic nano material by arc discharge method	14	14	19	47
75	15911A0372	GAUTE VARUN TEJ	Restoration of damaged component using reverse engineering and rapid prototyping	14	14	19	47
76	15911A0373	GOPALA SAI KIRAN	Evaluation of mechanical properties of jute polyester composites	13	14	18	45
77	15911A0374	JAINIL R SAVLA	Restoration of damaged component using reverse engineering and rapid prototyping	14	15	19	48
78	15911A0375	K VAMSI GOUD	Friction stir welding by similar and disimilar methods	14	14	18	46
79	15911A0376	K VARUN TEJA	Design development of air cushion vehicle	13	14	19	46
80	15911A0377	KALAL VINAY KUMAR GOUD	Performance of emission chracteristics of IC engine using alterante fuel	13	13	19	45
81	15911A0379	KELOTH PURNACHANDRA NAIK	Performance and emission characteristic of dual fuel diesel engine with cotton seed oil and CNG	13	14	19	46
82	15911A0380	KOMANDLA VENKATRAM REDDY	Evaluation of mechanical properties of jute polyester composites	12	14	18	44
83	15911A0381	KONDA SUMANTH	Friction stir welding by similar and disimilar methods	14	14	18	46
84	15911A0382	KURAPATI LOKESH	Impact of post weld heat treatment on the mechanical properties of super duplex stainless steel	13	14	19	46
85	15911A0385	M SAI VIJAY	Reatader breaking system	11	11	15	37
86	15911A0386	MADAVENA ROSHITH	Performance of emission chracteristics of IC engine using alterante fuel	14	14	18	46
87	15911A0388	MOHAMMAD ASIF	Friction stir welding by similar and disimilar methods	14	14	18	46
88	15911A0389	MOHAMMED SOHAIL	Failure analysis of alloy wheel with reverse engineering approach	14	15	19	48
89	15911A0390	MOHAMMED UMAIR AHMED	Study of magnatic nano material by arc discharge method	14	14	19	47
90	15911A0391	MUMMIDIVARAPU NAGA SATISH	Friction stir welding by similar and disimilar methods	13	14	18	45
91	15911A0392	MUSAB MOHAMMED ABDULLAH	Study of magnatic nano material by arc discharge method	14	14	19	47
92	15911A0394	NIKHIL KUMAR REDDY VANIPENTA	Study of composite materials - cotton impregnation with Ag-Nano particles	13	14	19	46
93	15911A0395	PENDLI RAKESH	Performance and emission characteristic of dual fuel diesel engine with cotton seed oil and CNG	13	14	19	46
94	15911A0396	PONNA NAGARJUNA	Evaluation of mechanical properties of jute polyester composites	13	14	18	45
95	15911A0397	SADHULA RAMESH	Performance and emission characteristic of dual fuel diesel engine with cotton seed oil and CNG	14	14	18	46
96	15911A03A0	SHIVANATHRI RAHUL	Performance of emission chracteristics of IC engine using alterante fuel	14	13	19	46
97	15911A03A1	THINDERU SHASHANK	Impact of post weld heat treatment on the mechanical properties of super duplex stainless steel	14	14	19	47
98	15911A03A2	VANGARI CHANDRA SHEKAR	Impact of post weld heat treatment on the mechanical properties of super duplex stainless steel	13	14	19	46
99	15911A03A3	VANKADOTH RAVI CHANDRA NAIK	Restoration of damaged component using reverse engineering and rapid prototyping	15	15	19	49
100	15911A03A4	VANKUDOTH SUNIL	Study of composite materials - cotton impregnation with Ag-Nano particles	13	14	19	46
101	15911A03A5	VEMUNOORI ANANTHA REDDY	Study of composite materials - cotton impregnation with Ag-Nano particles	12	14	19	45
102	15911A03A6	VISHNU SINGH	Design manufacturing nad cost analysis of wall mounted bicycle stand	14	15	19	48
103	15911A03A8	YADAVULA DEVENDAR	Reatader breaking system	11	11	15	37
104	16915A0313	GADE JAGADISH	Performance of double receiver compound parabolic concentrator	12	14	17	43
105	16915A0314	GOUNDLA PRABHAKAR GOUD	Design development of air cushion vehicle	14	14	18	46
106	16915A0315	GOUNI MANOJKUMAR	Impact of post weld heat treatment on the mechanical properties of AISI 316L welded joint	13	13	17	43
107	16915A0316	GUDIPUDI SUMAN	Performance of double receiver compound parabolic concentrator	13	13	18	44
108	16915A0317	GUMMADIDALA MALLIKARJUN	Impact of post weld heat treatment on the mechanical properties of AISI 316L welded joint	14	14	18	46
109	16915A0318	J BHARATH	Impact of post weld heat treatment on the mechanical properties of AISI 316L welded joint	14	13	18	45
110	16915A0319	K HARSHA VARDHAN REDDY	Design development of air cushion vehicle	13	14	19	46
111	16915A0320	K PRADEEP REDDY	Performance of double receiver compound parabolic concentrator	12	13	18	43
112	16915A0321	K PRASAD	Residual stress analysis of super duplex stainless steel welded joints using XRD	14	14	18	46
113	16915A0322	KANUGANTI SAINATH	Impact of post weld heat treatment on the mechanical properties of AISI 316L welded joint	13	14	18	45
114	16915A0323	KATIKE VISHNU VARDHAN	Residual stress analysis of super duplex stainless steel welded joints using XRD	14	13	18	45
115	16915A0324	KODAVALLY MAHESH	Residual stress analysis of super duplex stainless steel welded joints using XRD	13	14	18	45
116	14911A0315	CHILLA KIRAN KUMAR (Re-Admn dt 13/06/2017)	Comparitive analysis of mechanical properties of abaca and banana fiber	13	13	17	43

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

Date: 17.04.2019

CIRCULAR

As an initiative by the department of mechanical engineering in the identification of best projects, a selection committee has been constituted to review and scrutinize all the projects for the academic year 2018-2019, based on following factors.

1. Creativity
2. Type of Materials used
3. Manufacturing Methods Employed
4. Experimentation results through design of experiments
5. Analysis of results
6. Conclusion

The prospective projects selected are taken for award to be conferred on graduation day.

The committee members are:

1. Dr. V.V. Satyanarayana
2. Dr.B.V Reddy
3. Mr.M.Naveen Kumar

HoD/MECH

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

Date: 26.04.2019

CIRCULAR

After thorough reviewing of all the projects by considering following factors, the committee members has selected the best projects for which award is to be conferred on 22.04.2019.

1. Creativity
2. Type of Materials used
3. Manufacturing Methods Employed
4. Experimentation results through design of experiments
5. Analysis of results
6. Conclusion

The Best Projects are:

S.NO	H.T.No.	NAME OF THE STUDENT	PROJECT TITLE	GUIDE
I	16915A0331	NALLAVELLI SRIKANTH	Design and analysis of 3D printed lattice structures	Dr.V.Phanindra Bogu
	16915A0327	MOHAMMAD IMRAZ		
	16915A0325	MACHARLA SHRAVAN KUMAR		
	15911A03B7	BASHABOINA PRASHANTH		
II	15911A03A3	RAVI CHANDRA	Restoration of damaged component using reverse engineering and rapid prototyping	Dr.G.Sreeram Reddy
	15911A0372	VARUN TEJ		
	15911A0364	KARTHIK		
	15911A0374	JAINIL		
III	15911A0335	K.Sai Kumar	Effect of Al2O3 and C40 performance of single slope solar still	Dr.L.Madan Kumar
	15911A0318	D.Vikram		
	15911A0331	K.Jayanth		
	15911A0324	G.Amarendar		

HoD/MECH

A PROJECT REPORT

ON

Restoration of damaged component using Reverse Engineering and Rapid prototyping

Submitted for partial fulfillment of the requirements for the award of the degree

Of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

RAVI CHANDRA NAIK (15911A03A3)
JAINIL SAVLA (15911A0374)
G. VARUN TEJ (15911A0372)
C. KARTHIK (15911A0364)

Under the guidance of
Dr. G. Sreeram Reddy
Professor
Department of Mechanical Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

(Autonomous)

AZIZNAGAR, CHILKUR ROAD, HYDERABAD-**500075**

CERTIFICATE

This is to certify that the project work entitled "**Restoration of damaged component using Reverse Engineering and Additive prototyping**" is a bonafide project work submitted by **RAVI CHANDRA NAIK (15911A03A3), JAINIL SAVLA (15911A0374) G.VARUN TEJ (15911A0372) C. KARTHIK (15911A0364)** in partial fulfillment of requirements for the award of degree of **Bachelor of Technology in Mechanical Engineering** by the **JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY,** Hyderabad, under our guidance and supervision.

The results embodied in this report have not been submitted to any other university or institute for the award of any degree or diploma.

INTERNAL GUIDE
Dr. G. Sreeram Reddy
Professor
Department of Mechanical
Engineering, VJIT, Hyderabad.

HEAD OF DEPERMENT
Dr. G. Sreeram Reddy
Department of Mechanical
Engineering, VJIT, Hyderabad.

17/4/19

External Examiner

DECLARATION

This is to certify that the work reported in the present project entitled "Restoration of damaged component using Reverse engineering and Additive prototyping" is a record of work done by us in the Department of MECHANICAL ENGINEERING, Vidya Jyothi Institute of Technology (Autonomous), Jawaharlal Nehru Technological University, Hyderabad. The reports are based on the project work done entirely by us and not copied from any other source.

Ravi Chandra naik

Jainil Savla

G.Varun Tej

C. Karthik

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and indebtedness to my project supervisor Dr. G. SREERAM REDDY for his valuable suggestions and interest throughout the course of this project.

I am also thankful to Director Dr. P. VENUGOPAL REDDY, Principal Dr. A. PADMAJA and Head of the department Dr. G. SREE RAM REDDY for providing excellent infrastructure and a nice atmosphere for completing this project successfully

I convey my heartfelt thanks to the lab staff for allowing me to use the required equipment whenever needed

Finally I would like to take this opportunity to thank my family for their support through the work. I sincerely acknowledge and thank all those who gave directly or indirectly their support in completion of this work

Abstract

This present project gives a compilation of work related to reconstruction of a damaged "FOOT VALVE MESH" utilizing the reverse engineering process to scan and transfer the geometry of part into a useful 3D dimensional model that can be sent to 3D printer and turned into an actual physical part. Also the computer model is converted to 3D computed aided design (CAD) model to perform the alignment test and validate the liability of the part in the real world condition. The process includes the utilizing of faro arm laser scanning, reverse engineering software, 3D printer.

The Laser scanner and reverse engineering creates a 3D model of the part which is used as basic model for the manufacturing process in addition the 3D printer is utilized to create a prototype of the part to ensure the manufacturability of the part early in design phase. Furthermore simulation software is used for performing alignment and making recommendation to improve the liability of the part. The deviation are assessed by 2D and 3D comparison to domain of the part can be properly handled in real time circumstances. Finally under tolerances among the 3D and 2D compare values obtained are minimum.

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CHAPTER-I

INTRODUCTION

In today's considerably growing competitive global market, product enterprises are constantly seeking new ways to shorten lead times for new product developments that meet all customer expectations. Engineering fields are constantly improving upon current designs and methods to make life simple and easier. When referring to technology, simple and easy can be directly related to fast and accurate.

This Thesis describes a complete prototyping process using the Reverse Engineering techniques. The geometry of a mechanical component is captured using digitizing arm and Reverse Engineering (RE) software. The Rapid prototyping process used is Fused Deposition Modeling (FDM) system. It also describes the step-by-step procedure for making the prototype as well as the hardware and software used for making the prototype model.

When we think of engineering we think of the general meaning of designing a product from a blue print or plan. Engineering is described as "the application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems". This type of engineering is more commonly known as Forward Engineering. An emerging engineering concept is utilizing forward engineering in a reverse way. This method is more commonly referred to as Reverse Engineering.

Reverse engineering is the opposite of forward engineering. It is the process of analyzing a subject system to create representations of the system at a higher level of abstraction. It can also be seen as going backwards through the development cycle. Reverse engineering is taking apart an object to see how it works in order to duplicate or enhance the object. It takes an existing product, and creates a CAD model, for modification or reproduction to the design aspect of the product.

With this knowledge, computer vision applications have been tailor to compete in the area of reverse engineering. Computer vision is a computer process concerned with artificial intelligence and image processing of real world images. Typically, computer vision requires a combination of low-level image processing to enhance the image quality (e.g. remove noise, increase contrast) and higher level pattern recognition and image understanding to recognize features present in the image. Three-dimensional (3D) computer vision uses two-dimensional (2D), images to generate a 3D model of a scene or object.

The impact of reverse engineering plays a significant role in promoting industrial evolution. The life cycle of a new invention usually lasted for centuries in ancient times. It took thousands of years to invent the electric light bulb for the replacement of the lantern. Both industry and society accepted this slow pace. However, the average life cycle of modern inventions is much shorter. It has only taken a few decades for the invention of the digital camera to replace the film camera and instant camera. This has led to a swift evolution of the photo industry.

In general, product enterprise has invested in CAD/CAM, rapid prototyping, and a range of new technologies that provide business benefits. Reverse engineering (RE) is now considered one of the technologies that provide business benefits in shortening the product development cycle. Figure 1.1 below depicts how RE allows the possibilities of closing the loop between what is “as designed” and what is “actually manufactured”.

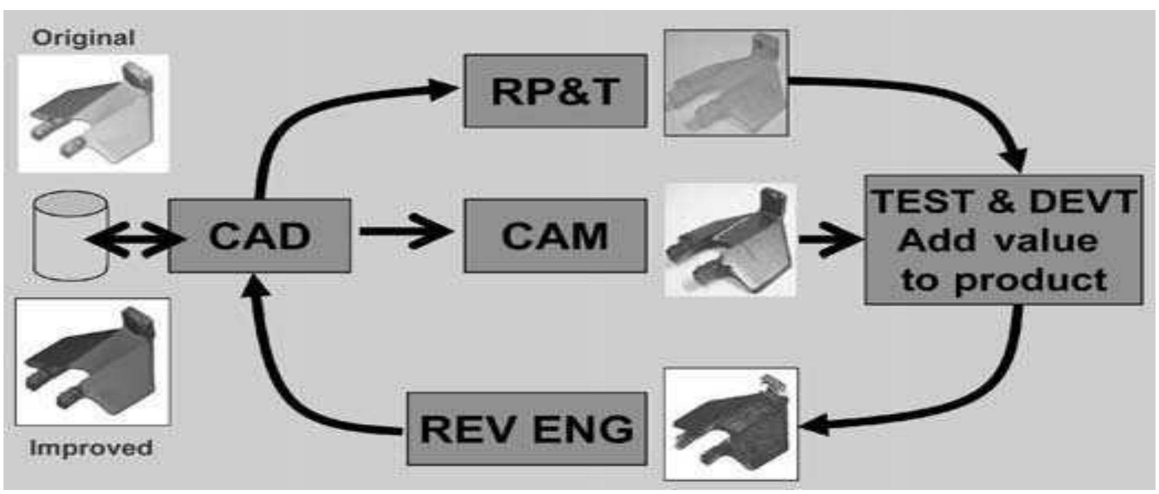


Figure 1.1 Product development cycle

1 Reverse engineering

1.1 Introduction

Reverse engineering (RE) is a process of measuring, analyzing, and testing to reconstruct the mirror image of an object or retrieve a past event. It is a technology of reinvention, a road map leading to reconstruction and reproduction. It is also the art of applied science for preservation of the design intent of the original part.

Reverse engineering can be applied to re-create either the high-value commercial parts for business profits or the valueless legacy parts for historical restoration. To accomplish this task, the engineer needs an understanding of the functionality of the original part and the skills to replicate its characteristic details. Though it roots back to ancient times in history, the recent advancement in reverse engineering has elevated this technology to one of the primary methodologies utilized in many industries, including aerospace, automotive, consumer electronics, medical device, sports equipment, toy, and jewelry. It is also applied in forensic science and accident investigations. Manufacturers all over the world have practiced reverse engineering in their product development. The new analytical technologies, such as three-dimensional (3D) laser scanning and high-resolution microscopy, have made reverse engineering easier, but there is still much more to be learned.

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.

Reverse engineering provides a solution to this problem because the physical model is the source of information for the CAD model. This is also referred to as the physical-to-digital process. Another reason for reverse engineering is to compress product development cycle times. In the intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead times to market a new product. Rapid product development

(RPD) refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of shortened product development time. For example, injection-molding companies need to shorten tool and die development time drastically. By using reverse engineering, a three-dimensional physical product or clay mock-up can be quickly captured in the digital form, remodeled, and exported for rapid prototyping/tooling or rapid manufacturing using multi-axis CNC machining techniques.

1.2 Reverse Engineering–The Generic Process

The generic process of reverse engineering is a three-phase process as depicted in Figure 1.2. The three phases are scanning, point processing, and application specific geometric model development. Reverse engineering strategy must consider the following:

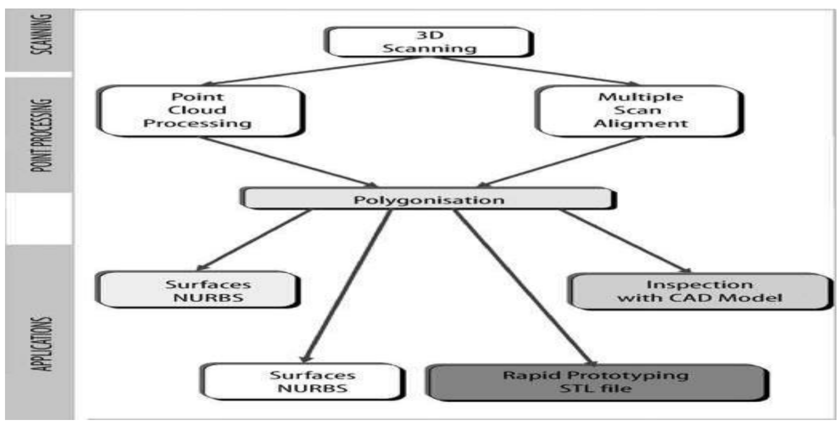


Figure 1.2 Reverse engineering – the generic process

- Reason for reverse engineering a part
- Number of parts to be scanned–single or multiple
- Part size–large or small
- Part complexity–simple or complex
- Part material–hard or soft
- Part finish–shiny or dull
- Part geometry–organic or prismatic and internal or external
- Accuracy required–linear or volumetric

1.2.1 Phase 1–Scanning instrument and technology

One of the biggest challenges of reconstructing a mechanical part is to capture its geometric details. Fortunately, advanced devices have been developed to image the three-dimensional features of a physical object and translate them into a 3D model with high accuracy. Data can be obtained directly using a digitizer that is connected to a computer installed with reverse engineering software. The two most commonly used digitizing devices are probes and scanners.

This phase is involved with the scanning strategy–selecting the correct scanning technique, preparing the part to be scanned, and performing the actual scanning to capture information that describes all geometric features of the part such as steps, slots, pockets, and holes. Three-dimensional scanners are employed to scan the part geometry, producing clouds of points, which define the surface geometry. These scanning devices are available as dedicated tools or as add-ons to the existing computer numerically controlled (CNC) machine tools.

1.2.2 Phase 2–Point Processing

This phase involves importing the point cloud data, reducing the noise in the data collected, and reducing the number of points. These tasks are performed using a range of predefined filters. It is extremely important that the users have very good understanding of the filter algorithms so that they know which filter is the most appropriate for each task. This phase also allows us to merge multiple scan data sets. Sometimes, it is necessary to take multiple scans of the part to ensure that all required features have been scanned. This involves rotating the part; hence each scan datum becomes very crucial. Multiple scan planning has direct impact on the point processing phase. Good datum planning for multiple scanning will reduce the effort required in the point processing phase and also avoid introduction of errors from merging multiple scan data. A wide range of commercial software is available for point processing.

The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format. This phase also supports most of the proprietary formats mentioned above in the scanning phase.

1.2.3 Phase 3–Application Geometric Model Development

In the same way that developments in rapid prototyping and tooling technologies are helping to shorten dramatically the time taken to generate physical representations from CAD models, current RE technologies are helping to reduce the time to create electronic CAD models from existing physical representations.

The need to generate CAD information from physical components will be arise frequently throughout any product introduction process.

The generation of CAD models from point data is probably the most complex activity within RE because potent surface fitting algorithms are required to generate surfaces that accurately represent the three-dimensional information described within the point cloud data sets. Most CAD systems are not designed to display and process large amounts of point data; as a result new RE modules or discrete software packages are generally needed for point processing. Generating surface data from point cloud data sets is still a very subjective process, although feature-based algorithms are beginning to emerge that will enable engineers to interact with the point cloud data to produce complete solid models for current CAD environments.

The applications of RE for generating CAD data are equally as important as the technology which supports it. A manager’s decision to employ RE technologies should be based on specific business needs. This phase depends very much on the real purpose for reverse engineering. For example, if we scanned a broken injection molding tool to produce a new tool, we would be interested in the geometric model and also in the ISO G code data that can be used to produce a replacement tool in the shortest possible time using a multi-axis CNC machine. One can also use reverse engineering to analyze “as designed” to “as manufactured”. This involves importing the as designed CAD model and superimposing the scanned point cloud data set of the manufactured part. The RE software allows the user to compare the two data sets (as designed to as manufactured). This process is also used for inspecting manufactured parts. Reverse engineering can also be used to scan existing hip joints and to design new artificial hips joint around patient- specific pelvic data. This creates the opportunity for customized artificial joints for each patient. 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.

1.3 Merits of reverse engineering

- It helps in the evolving of existing computing systems.
- You can change a programs structure and thus directly affects its logical flow. Technically this activity is called patching, because it involves placing new code patches (in a seamless manner) over the original code.

- Can be a learning tool.
- Can be used as a way to make new compatible products that are cheaper than what it is.
- Cost saving for developing new product because the model is available in advance
- An improvement on material to increase longevity
- Manufacture the part from one piece of material (no welds)
- Customized modification to suit your functionality of any given wear.

1.3 Demerits of reverse engineering

- Super small objects are difficult to reproduce due to current technologies limitation.
- You c never be disassembling an application fully to its original state before compiled.
- If the object is not decent condition i.e., due to wear, warping such things could difficult for getting good scan and requires lots of adjustment.
- There is a problem with patent issue of the design.

1.5 Reverse engineering application

Manufacturing engineering To create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE or other software.

- To make a digital 3D record of own product
- To asses competitors product
- To analyze the working of a product
- To identify potential patent infringement etc
- To analyze the working of a product
- To inspect and compare actual geometry with CAD model
- To measure wear of tools.

Software engineering To extract design & implementation information

- To detect and neutralize viruses and malware
- If the source code itself is not available for the software.

- Security auditing.
- Removal of copy protection.
- To detect and neutralize viruses and malware

Chemical engineering To determine chemical composition

- To substitute or improve recipes to stimulate or improve the product performance

Film-entertainment industry Animated objects are imparted motion using the reverse engineered human skeletons.

- For 3D scanning and rapid surfacing of scale models for animation and film sets.
- For 3D scanning to support online marketing and e presentations
- For bringing real life forms into virtual gaming industry

Medical field Applications in orthopedic, dental & reconstructive surgery

- Imaging, modeling and replication (as a physical model) of a patient's bone structure
- Root cannel of the teeth in dental operation
- Models can be viewed and physically handled before surgery, which gives benefit during evaluation of the procedure and implementation in difficult cases.
- Less risk to the patient had reduced cost through saving in theatre time

Aviation industry The introduction of CFM engine spare parts produced by reverse engineering for the repair and replacement of worn-out components will have significant economic impact on the aviation industry and its customers, who will have more options in their maintenance programs

- The PMA is rooted in the aviation industry. It is both a design approval and a product approval for the reproduction of OEM parts. The criteria of PMA approval are constantly updated along with the advancement of reverse engineering technology.

2 Reverse engineering- Hardware and Software

2.1 Introduction

RE hardware is used for RE data acquisition, which for 3-D modeling, is the collection of geometric data that represent a physical object. There are three main technologies for RE data acquisition: contact, noncontact and destructive. Outputs of the RE data acquisition process are 2-D cross-sectional images and point clouds that define the geometry of an object.

RE software is employed to transform the RE data produced by RE hardware into 3-D geometric models. The final outputs of the RE data processing chain can be one of two types of 3-D data: (i) polygons or (ii) NURBS (non- uniform rational B-splines). Polygon models, which are normally in the STL,

VRML, or DXF format, are commonly used for rapid prototyping, laser milling, 3- D graphics, simulation, and animations. NURBS surfaces or solids are frequently used in computer-aided design, manufacturing, and engineering (CAD-CAM-CAE) applications. Data can be obtained directly using a digitizer that is connected to a computer installed with reverse engineering software. The two most commonly used digitizing devices are probes and scanners. They both measure the part external features to obtain its geometrical and dimensional information.

2.2 Reverse Engineering Hardware

An important part to reverse engineering is data acquisition. Data acquisition systems are constrained by physical considerations to acquire data from a limited region of an objects' surface. Therefore, multiple scans of the surface must be taken to completely measure a part. After reviewing the most important measuring techniques, the related merits and difficulties associated with these methods are discussed. Figure 2.2 classifies the types of application used for acquiring 3D data into contact and non-contact methods

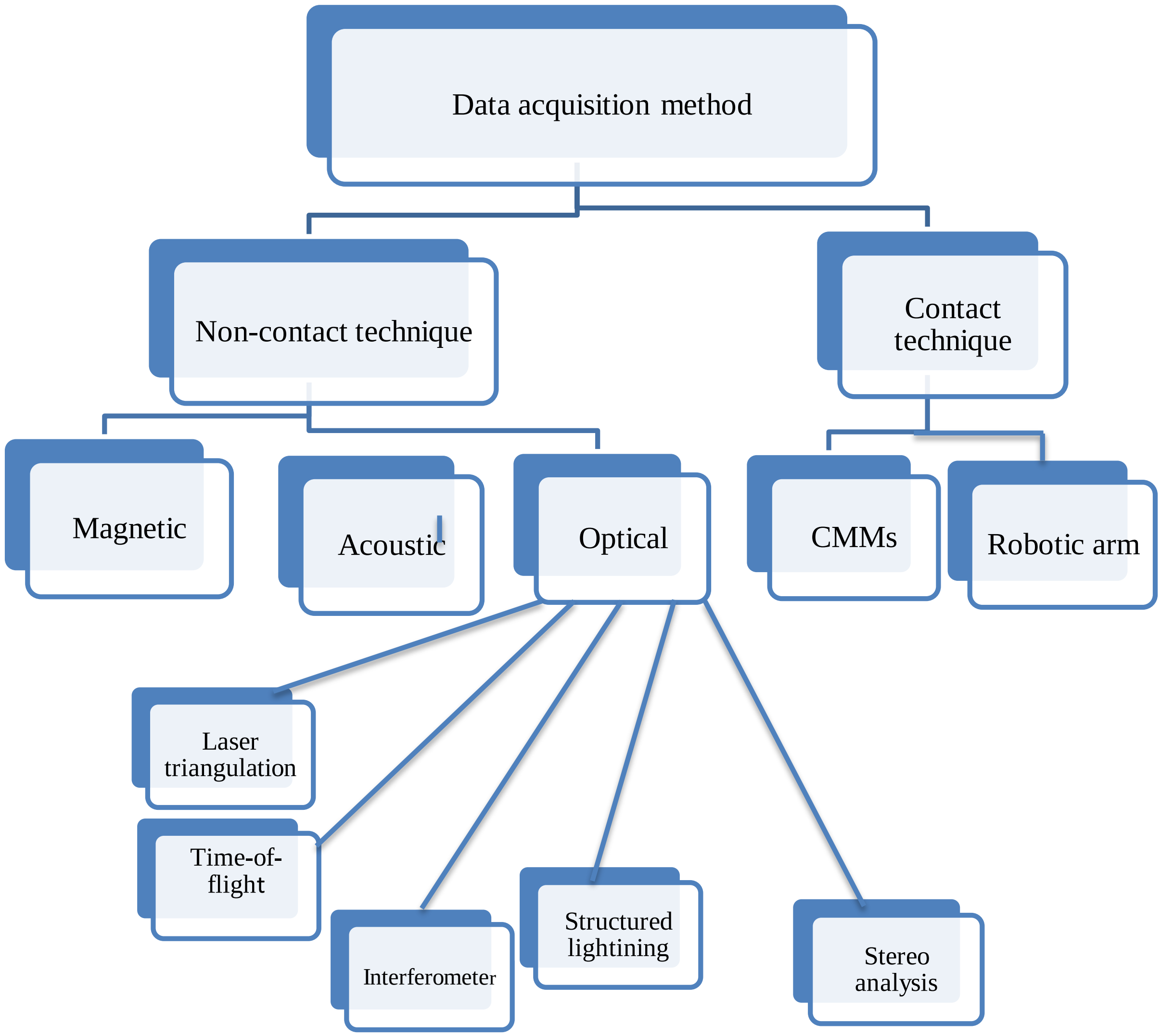


Figure 1.3 Methods in reverse engineering data scanning technique

2.2.1 Contact Methods

Contact methods use sensing devices with mechanical arms, coordinate -measurement machines (CMM), and computer numerical control (CNC) machines, to digitize a surface. There are two types of data collection techniques employed in contact methods.

(i) Point-to-point sensing with touch-trigger probes and

(ii) Analogue sensing with scanning probes.

In the point-to-point sensing technique, a touch-trigger probe is used that is installed on a CMM or on an articulated mechanical arm to gather the coordinate points of a surface. A manually operated, articulated mechanical arm with a touch-trigger probe allows multiple degrees of freedom (DOF) of movement to collect the measurement points (Figure 2.2). A CMM with a touch-trigger probe can be programmed to follow planned paths along a surface. A CMM provides more accurate measurement data compared to the articulated arm. However, the limitation of using CMM is the lack of number of DOF so that a CMM cannot be used to digitize complex surfaces in the same way as an articulated arm.

A 3-axis milling machine is an example of a mechanical or robotic arm. These machines can be fitted with a touch probe, as mentioned before, and used as a tactile measuring system. However, it is not very effective for concave surfaces. There are many different other robotic devices which are used because of their ability to have less noise and have a desirable accuracy, but like the CMM, they are the slowest method for data acquisition.

There are disadvantages when using a CMM or robotic arm to model surfaces of parts. The disadvantages of CMMs having contact to the surface of an object can damage the object. The reason being is if the surface texture is soft, holes can be inflicted on the surface. CMMs also show difficulties in measuring parts with free form surfaces. The part might have indentions that are too small. Flexibility of parts makes it very difficult to contact the surface with a touch probe without creating an indentation that detracts from the accuracy of the measurements.

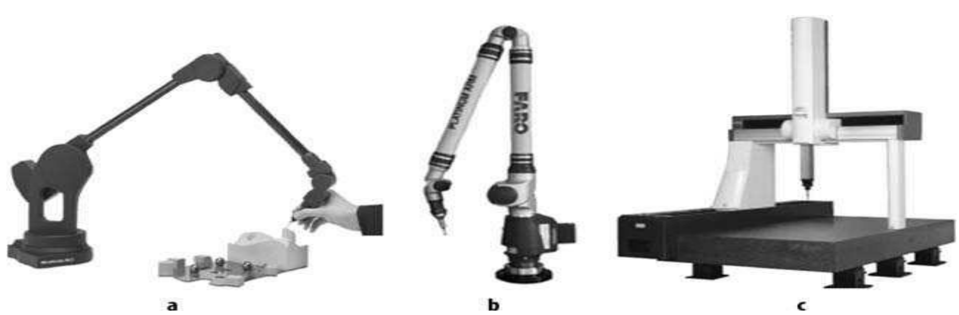


Figure 1.4 (a) Micro Scribe MX Articulated Arm from Immersion Corporation. (b) Faro Arm–Platinum articulated arm from FARO Technologies. (c) Mitutoyo CMM machine–CRA Apex C model

Table 1.1 Gives examples of typical commercial RE hardware that employs contact methods for data acquisition.

Technology	**Company**	**Model**	**Volume (mm)**	**Accuracy, resolution and speed**	**Operation**
Point-to point sensing with a touch-trigger probe, mechanical arms	Faro Technologies	Faro Arm Advantage	1200-3700	Accuracy: ±0.090 to ± 0.431 mm	Manual
		Faro arm platinum	1200-3700	Accuracy: ±0.018 to ± 0.086 mm	
	Immersion corp.	Micro scribe MX	1270	Accuracy; 0.1016mm	Manual
		Micro scribe MLX	1670	Accuracy;0.1270 mm	
Analogue sensing with a scanning probe, CNC machines	Roland DGA Corp.	Picza PIX-30	305×203 × 60	Scan pitch in Y,Y,Z axis: + (X, Y): 0.05–5.0 mm in Steps of 0.05 mm. + Z: 0.025 mm	Programmed
		MDX-15	150×100 × 60		
		MDX-20	200×150 × 60		
Analogue sensing with a scanning probe, CMM and CNC machines	Renishaw Inc.	Renscan 200	Based on the CMM and CNC machine volume	+ Speed: 508–1016 mm/min + Max data rate: 70 points/s	programmed
Point-to-point sensing with a touch- trigger probe, CMM	Mitutoyo	Euro-c-121210	1205*1205*1005	Accuracy;0.001 mm	programmed

2.2.2 Noncontact Methods

In noncontact methods, 2-D cross-sectional images and point clouds that represent the geometry of an object are captured by projecting energy sources (light, sound, or magnetic fields) onto an object; then either the transmitted or the reflected energy is observed. The geometric data for an object are finally calculated by using triangulation, time-of-flight, wave-interference information, and image processing algorithms. There is no contact between the RE hardware and an object during data acquisition.

There are different ways to classify RE hardware that uses noncontact RE methods for data acquisition. These classifications are based on the sensor technologies or data acquisition techniques employed. Figure 3.4 presents a classification of noncontact RE hardware based on data acquisition techniques. The advantages and disadvantages of noncontact methods compared to contact methods are as follows.

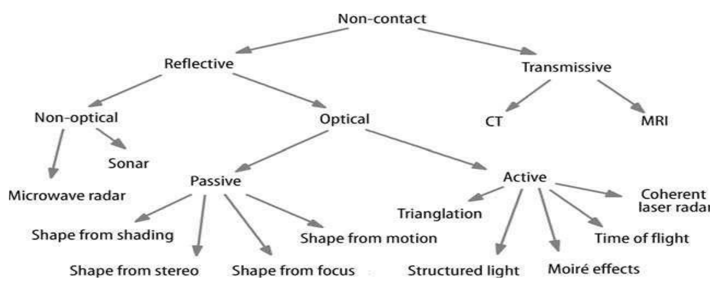


Figure 1.5 Non-contact methods classification

Advantages

(i) No physical contact;

(ii) Fast digitizing of substantial volumes;

(iii) Good accuracy and resolution for common applications;

(iv) Ability to detect colors; and

(v) Ability to scan highly detailed objects, where mechanical touch probes may

Be too large to accomplish the task.

Disadvantages

(i) Possible limitations for colored, transparent, or reflective surfaces and
(ii) Lower accuracy

Optical methods

Optical method of shape capture is probably the broadest and growing in popularity over contact methods. This is because they have relatively fast acquisition rates. There are five important categories of optical methods: laser triangulation, time-of-flight, interferometers, structured lighting and stereo analysis. This section will discuss the various principles of each method.

Magnetic

Magnetic field measurement involves sensing the strength of a magnetic field source. Magnetic touch probes are used which usually sense the location and orientation of a stylus within the field. A trigger allows the user to only record specific point data once the stylus is positioned at a point of interest. Magnetic resonance is used in similar applications to ultra-sound when internal material properties are to be measured. MRI (magnetic resonance) activates atoms in the material to be measured and then measures the response

Laser Triangulation

Most laser scanners use straightforward geometric triangulation to determine
The surface coordinates of an object. Triangulation is a method that employs
Locations and angles between light sources and photosensitive devices (CCD–
Charge-coupled device camera) to calculate coordinates

Two types of triangulation methods

1. Single camera arrangement

In a single camera system, a device transmits a light spot (or line) on the object at a defined angle. A CCD camera detects the position of the reflected point (or line) on the surface.

2. Double camera arrangement

In a double camera system, Two CCD cameras are used. The light projector is not involved in any Measuring functions and may consist of a moving light spot or line, moving Stripe patterns, or a static arbitrary pattern.

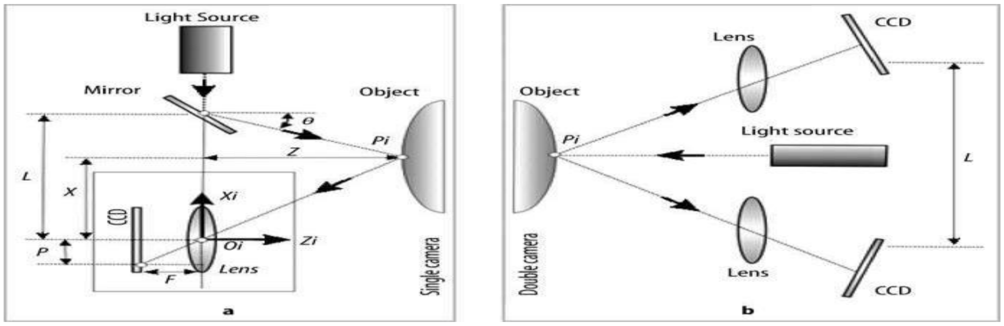


Figure 1.6 Triangulation methods: (**a**) single and (**b**) double camera arrangement

The principle of the triangulation method is shown in Figure 3.5a. A high energy light source is focused and projected at a pre-specified angle (θ) onto the surface of an object. A photosensitive device senses the reflection from the illuminated point on the surface. Because the fixed baseline length (*L*) between the light source and the camera is known from calibration, using geometric triangulation from the known angle (θ), the focal length of the camera (*F*), the image coordinate of the illuminated point (*P*), and fixed baseline length (*L*), the position of the illuminated point (*Pi*) with respect to the camera coordinate system can be calculated as follows

$$z = FL/(P+F\tan\theta)$$

$$X = L - Z \tan\theta$$

The measurement errors in *P* and θ can be determined from the following

Equation:

$$\Delta Z = (Z^2/FL)\times\Delta P\times(Z^2 \sec^2\theta/L)\times\Delta\theta$$

The error in the *Z* measurement is directly proportional to *Z*2 but inversely proportional to the focal length and the baseline length. Therefore, increasing the baseline length can produce higher accuracy in the measurement. For practical reasons, the baseline length cannot be increased at will, and it is limited by the hardware structure of the scanners. Therefore, triangulation scanners are commonly used for scanning small objects over short distances. If the single-point or sheet-of-light pattern is used as the light source, the triangulation scanner is mounted on the travel platform so that it can produce multiple surface scans. Triangulation scanners are supplied both as complete systems and as self-contained scanning heads for mounting on standard touch probe arms or CMMs.

Time of Flight

The principle behind all time-of-flight implementations is to measure the amount of time (t) that a light pulse (i.e., laser electromagnetic radiation) takes to travel to the object and return. Because the speed of light (C) is known, it is possible to determine the distance traveled. The distance (D) of the object from the laser would then be equal to approximately one half of the distance the laser pulse traveled

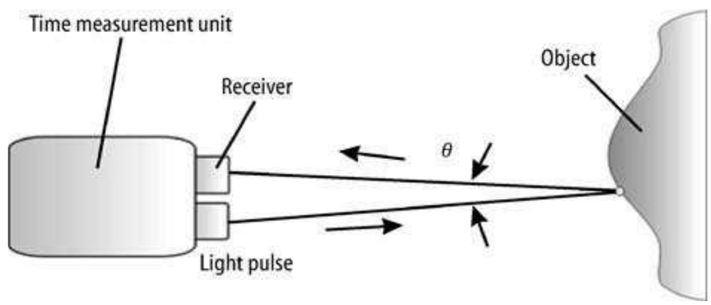


Figure 1.7 Principle of TOF scanners

For all practical purposes, the angle θ is very small and thus has no effect on the accuracy of the TOF distance measurement. The high velocity of light allows TOF scanners to make hundreds, or even thousands of measurements per second.

Advantages

1. They can digitize large distant objects such as buildings and bridges.

2. The accuracy of RE hardware based on TOF is reasonable and approximately between a few millimeters and two or three centimeters for long-range scanners.

3. The shorter the pulse and the faster the detector, the higher the accuracy of the measurement.

Disadvantages

1. TOF scanners are large and do not capture an object's texture, only its geometry.

2. They are not practical for fast digitization of small and medium-sized objects.
3. They are not practical for fast digitization of small and medium-sized objects.
4. Moreover, it takes time to complete the digitization process because the object (or environment) has to be swept during scanning.

Structured light

In structured-light techniques a light pattern is projected at a known angle onto the surface of interest and an image of the resulting pattern, reflected by the surface, is captured. The image is then analyzed to calculate the coordinates of the data point on the surface. A light pattern can be (i) a single point; (ii) a sheet of light (line); and (iii) a strip, grid, or more complex coded light (Figure 3.6).

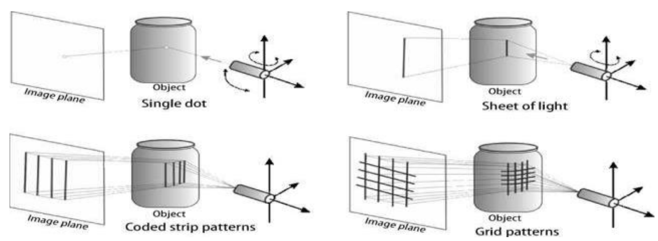


Figure 1.8 Different light patterns used in structured-light techniques

The most commonly used pattern is a sheet of light that is generated by fanning out a light beam. When a sheet of light intersects an object, a line of light is formed along the contour of the object. This line is detected and the X, Y, Z coordinates of hundreds of points along the line are simultaneously calculated by triangulation. The sheet of light sweeps the object as the linear slide carrying the scanning system moves it in the *X* direction while a sequence of images is taken by the camera in discrete steps. An index number k is assigned to each of the images in the order they are taken. Therefore, each k corresponds to the X position of the sheet of light. For each image *k*, a set of image coordinates (*i*, *j*) of the pixels in the illuminated stripe is obtained. The triples (*i*, *j*, *k*) are the range image coordinates; they are transformed to (*x*, *y*, *z*) world coordinates using a calibration matrix.

Advantages

(i) The data acquisition is very fast (up to millions of points per second)

(ii) Color texture information is available

(iii) Structured-light systems do not use a laser.

Acoustic

Where sound is reflected from a surface, *magnetic*, where a magnetic field touches the surface and a hybrid of both contact and non-contact. Acoustic methods have been used for decades for distance measuring. Sonar is used extensively for this purpose. Automatic focus cameras often use acoustic methods to determine range. The method is essentially the same as time-of-flight, where a sound source is reflected off a surface and then distance between the source and surface is determined knowing the speed of sound. Acoustic interference or noise is often a problem as well as determining focused point locations. Dynamic imaging is used extensively in ultra-sound devices where a transducer can sweep cross-sections through an object to capture material data internal to an object.

Stereo Image Analysis

The final optical shape capture method of interest is stereo image analysis. This is similar to structured lighting methods in that frames are analyzed to determine coordinate data. However, the analysis does not rely on projected patterns. Instead, typically, stereo pairs are used to provide enough information to determine height and coordinate position. This method is often referred to as a passive method since no structured lighting is used. Active methods are distinguished from passive methods in that artificial light is used in the acquisition of data. Correlation of image pairs and landmarks within the images are big difficulties with this method and this is why active methods are preferred. Another stereo image analysis approach deals with lighting models, where an image is compared to a 3D model. The model is modified until the shaded images match the real images of the object of interest. Finally, intensity patterns within images can be used to determine coordinate information.

Interferometer

Methods measure the distance in terms of wavelengths using interference patterns. This can be a very accurate method of measurement since visible light has a wavelength of the order of hundreds of nanometers, while most reverse engineering applications distances are in the centimeter to meter range. In principle, other parts of the electromagnetic spectrum could also be used. In practice, a high-energy light source is used to provide both a beam of monochromatic light to probe the object and a reference beam for comparison with the reflected light. Moring et al., describe a range finder based on time-of-flight calculations. The article presents some information on accuracy and performance. Jarvis presents an in-depth article on time-of- flight range finders giving detailed results and analysis.

To conclude this section, all measuring methods must interact with the surface or internal material using some phenomenon, either light, sound, magnetism or physical surface contact. The speed with which the phenomenon operates as well as the speed of the sensor device determines the speed of the data acquisition. The sensor type selected also determines the amount of analysis needed to compute the measured data and the accuracy

2.2.3 General Constraints of Data Acquisition Techniques

There are many practical problems with acquiring useable data, the major ones being:

1. Calibration

2. Accuracy

3. Accessibility

4. Occlusion

5. Fixture

6. Multiple views

7. Noise and incomplete data

8. Statistical distribution

9. Surface finish

2.3 REVERSE ENGINEERING SOFTWARE

2.3.1 Introduction

Software reverse engineering is defined as "the process of analyzing a subject system to create representations of the system at a higher level of abstraction". Abstraction is a concept or idea without affiliation with any specific instance. In software development, the higher abstraction levels typically deal with concept and requirement, while the lower levels accentuate design and implementation. Generally speaking, reverse engineering performs transformations from a lower abstraction level to a higher one, restructuring transformations within the same abstraction level; while forward engineering performs transformations from a higher abstraction level to a lower one.

2.3.2 Reverse engineering software classifications

There is no single RE software that can completely satisfy the requirements of RE data processing and geometric modeling. The selection of RE software depends on the specific requirements of RE projects

s.no	Application	Main function	Software
1.	Hardware control	Control RE hardware for data Acquisition. Normally, basic data Processing operations and data Conversion are also provided.	Mitutoyo Cosmos, Hymarc, Metris Scan, Cyber ware CyDir and GSI Crystal Studio.
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.	ICEM surf, Image ware and other common CAD Packages such as UG, Pro Engineer and Solid works.

3.	Polygon manipulation	3-D polygon data editing, Modification and optimization.	Magic's RP, DeskArtes, Catia Shape Sculptor and Viscam 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, Rapid form, Geomagics, Polyworks (Modeler) and Paraform.
5.	2-D Scan Image Processing and 3-D modeling	Used for processing 2-D scan images (CT/MRI) and 3-D reconstruction.	Mimics, Rapidform, Bio Build, Velocity2, Amira, Scan IP, Analyze and 3-D Doctors.
6.	3-D Inspection	Used for 3-D inspection, error map creation and analysis, inspection report and Documentation.	COMET inspect, Metris Focus Inspection, Power INSPECT, Polyworks Inspector and Geomagic Qualify.
7.	NURBS surface and solid modeling	Provide NURBS modeling and editing tools based on basic CAD Entities and primitives.	Pro Engineers, UG, Solid works, Catia and Rhino.

Table 1.2 Reverse engineering software classification based on application

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 Modeling, 3-D inspection, and NURBS surface and solid modeling. Table 3.1 presents these RE software groups with representative commercial packages.

2.3.3 Reverse Engineering Phases

For an overall view of RE software operation, the different RE data processing phases will first be described. The required RE operations are then considered. The complete RE data processing chain, from scan data to the final NURBS model, can be divided into four main phases: points and images, polygon, curves, and NURBS surfaces. Figure 3.1 presents the four phases of the RE data processing chain with the fundamental RE operations. These RE operations are necessary and are available with the most commonly used commercial RE software such as GSI Studio, Geomagics, Copy CAD, Rapidform, Polyworks, Paraform, ICEM surf, and Magic's RP.

Points and image phase In the points and images phase, scan data are registered, prepared, and optimized for constructing 3-D polygon models. Outputs from the RE data acquisition process are 2-D cross-sectional images or point clouds. RE systems that use transitive techniques such as CT and MRI provide a large series of 2-D cross-sectional images of an object.

Polygon phase In this phase, polygon models are constructed. They are then manipulated and controlled to meet the requirements of the applications. The resulting 3-D polygon models are directly employed for rapid prototyping or are used as reference data for creating CAD entities (points, curves, and primitives) and constructing NURBS surface

Curve phase In many RE projects, especially RE of mechanical parts, CAD entities are mainly used as the reference data for geometric modelling in CAD packages. The CAD entities are constructed directly from point clouds or indirectly from polygon models by manual editing, fitting, and sectioning operations.

NURBs surface NURBS surfaces are sometimes the ultimate RE output for CAD-CAM-CAE applications. NURBS surfaces can be constructed based on the CAD entities extracted from the curve phase or by using polygon meshes for surface fitting

Point and image phase

Registration Manual and automatic alignment.
Data optimization Noise and point redundancy reduction, sampling points and identifying primitives.
Basic operation Rotate and move, datum control and separating and merging.
Image processing Region growing and thresholding

Polygon phase

Polygon optimization Noise reduction and cleaning, abnormal phases cleaning
Polygon edit and control Filling holes, defeaturing, edge detection and sharpening control, primitives fitting, polygon editing and remeshing
Basic operation Rotate and move, datum control, Boolean, offset, shell, thicken, cut and merge

Curve phase

Primitive fitting: circle, cylinder and plane.
Curves construction: cross-section and curve fitting from points.
Curve modification and editing: curve re-parameterization, curve degree conversion, curve smooth and clean, control point edit, transition and extension, point generation and curve re-direction

NURBS surface phase

Surface from curve Loft, uv-network and extrude.
Patch creation & control Curvature detects, patch editing and patch temple re-use.
Nurbs surface creation & control Grids, Nurbs patches merging, Nurbs surface smoothing and editing
Evaluation Point to CAD, polygon to CAD, CAD to CAD

Figure 1.9 Four phases of the RE data processing chain with fundamental RE operations

3 Additive Prototyping

3.1 Introduction

The term additive prototyping (AP) refers to a class of technologies that are used to produce physical objects layer-by-layer directly from computer-aided design (CAD) data. It reflects one of the most distinctive features of this technology, much faster production of a tangible model part compared to traditional machining and other manufacturing processes. Prototyping revolutionizes the model part creation in machine design and reverse engineering, and provides designers with a tool to quickly convert a conceptual design idea into a physical model part. It helps engineers to visualize the design drawing and computer modeling. This process usually starts with the input of data from a CAD model that is an intermittent product of reverse engineering. A slicing algorithm first slices the CAD model into a number of thin layers and draws the detailed geometric information of each layer, and then transfers it to the prototyping machine. The final model part precision is directly related to the thickness of the slicing layers. For consistency, the STL format has been adopted as the industrial standard slicing algorithm. However, depending on the software, a CAD model can be built with various formats, such as DXF, 3DM, or IGES. Figure 1.10 a shows a simulated solid model of a sample part on the computer screen. This information is transferred to a 3D printer for prototyping, as shown in Figure 1.10 (a) figure 1.10 (b) Figure 1.10 (c) shows the final prototype part produced by the 3D printer.

Besides visual aids for communicating ideas with coworkers or customers, these prototypes can be used to test various aspects of their design, such as wind tunnel tests and dimensional checks. In addition to the production of prototypes, additive prototyping techniques can also be used to produce molds or mold inserts (rapid tooling) and even fully functional end-use parts (additive manufacturing).Because these are Nano prototyping application, rapid prototyping is often referred to as solid free-form fabrication or layered manufacturing.

Figure 1.10 Data transferring on the monitor screen

For small series and complex parts, these techniques are often the best manufacturing processes available. They are not a solution to every part fabrication problem. After all, CNC technology and injection molding are economical, widely understood, available, and offer wide material selection.

Depending on the dimensions of the object, production times can be as long as a few days, especially with complex parts or when long cooling times are required. This may seem slow, but it is still much faster than the time required by traditional production techniques, such as machining. This relatively fast production allows analyzing parts in a very early stage of designing, which decreases the resulting design cost.

3.2 General definition

The additive prototyping process is a nonconventional fabrication technology that is supported by modern information technologies for data conversion, CAD model building and slicing, and model part fabrication. This process usually starts with the input of data from a CAD model that is an intermittent product of reverse engineering. A slicing algorithm first slices the CAD model into a number of thin layers and draws the detailed geometric information of each layer, and then transfers it to the prototyping machine to build up semi-two-dimensional sections layer by layer with skinny thickness. The final model part precision is directly related to the thickness of the slicing layers. For consistency, the STL format has been adopted as the industrial standard slicing algorithm

However, depending on the software, a CAD model can be built with various formats, such as DXF, 3DM, or IGES. The DXF, short for drawing exchange or drawing interchange, format is a CAD data file format developed by Autodesk in 1982. For many years the data exchange with the DXF file has been challenging due to lack of specifications. The 3DM is a computer graphics software format developed for free-form NURBS modeling and to accurately transfer 3D geometry between applications. A direct application of the original point cloud data to slicing algorithm and layer modeling in additive prototyping technologies, if successfully developed, will have the potential to significantly improve the model part surface finishing, precision, and tolerance.

3.3 The Basic Process

Additive prototyping techniques share the following process steps (see Figure 1.11):

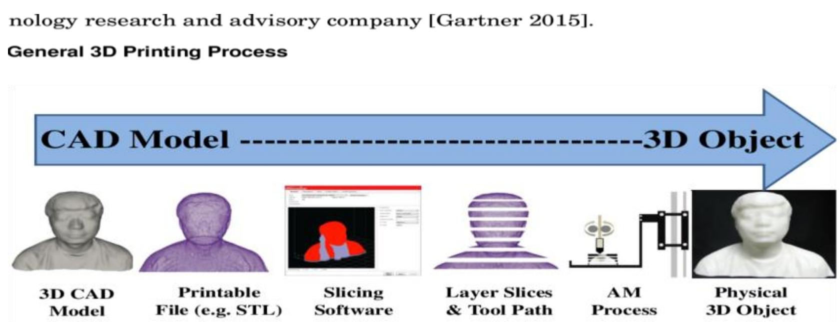


Figure 1.11 Basic process of additive prototyping

1. Creating a CAD model either by designing a new or scanning an existing object.

2. Converting the CAD data to STL format. Because the various CAD packages apply a number of different algorithms to represent solid objects, the STL format (Standard Triangulation Language) has been adopted as the standard of the rapid prototyping industry to establish consistency. This STL file is a concrete visualization of the product geometry, built up from triangles. Using triangles to describe a surface, curved surfaces can only be approached. Increasing the number of triangles (i.e., increasing the resolution) yields a better approach. However, it also enlarges the STL file. So, one has to find the optimum balance between file size and part accuracy.

3. Slicing the STL file into thin cross-sectional layers. After the STL file has been sized and oriented, it is sliced in layers with a predefined thickness.

4. Generation of a support structure. This additional step is not required for all techniques. Because the model is built up in layers, there may be areas that could float away or have

overhanging features, which could distort the resulting model. A base and support structures have to be added, which can be easily removed after the building step.

5. Producing the model layer-by-layer. The generated slices are reconstructed in the machine by building one layer at a time. This can be fully automatic.

6. Post processing, this step enhances cleaning and finishing the model and (if a base or support structure was built) removing the support structure. Some materials need to be post cured or infiltrated to achieve optimal properties

3.4 Current Techniques and Materials

A wide range of techniques and materials can be used for rapid prototyping. There are more than ten commercial rapid prototyping processes and more than five concept modeling processes; all have unique properties. Due to worldwide research, this range is growing quickly. Commercial techniques are available to produce objects from numerous plastics, ceramics, metals, and wood-like paper. Among these techniques are

• Stereo lithography

• Selective laser sintering

• Fused deposition modeling

• Three-dimensional printing

• Laminated object manufacturing

• Multijet modeling

• Laser-engineered net shaping

3.4.1 Stereo lithography

Stereo lithography (SLA) is the first commercialized additive rapid prototyping process, and is still the most widely used additive prototyping technology today. In U.S. Patent 4,575,330, “Apparatus for Production of Three-Dimensional Objects by Stereo lithography,” issued on March 11, 1986, Hull, who invented the technology of stereo lithography, defined it as a method and apparatus for making solid objects by successively "printing" thin layers of the ultraviolet curable material one on top of the other.

A platform is placed in a bath of photosensitive UV-curable resin at a level that leaves a small layer of resin between the top of the platform and the surface of the bath. A laser (often He-Cd or argon ion to produce UV radiation of about 320–370 nm wavelength) then strikes the desired areas, thereby curing the resin selectively. As the layer is completed, the platform descends allowing liquid resin to flow over the previously cured area. A wiper blade clears the excess fluid from the top of the surface. This sweep is essential to achieve consistent layer thickness and prevent air entrapment. As the new layer is cured, it sticks to the preceding layer. This process continues until the object is completed. On completion, the object raises above the fluid, so that resin can drain out. The object is carefully removed and washed in a solvent to remove uncured resin. The cleaned object has to be placed in a UV oven to ensure that all resin is cured. During the process, features that lean over have to be supported. This support structure can easily be generated by software and consists of a series of slender sacrificial columns or lattices.

Characteristics

• Long-term curing can lead to over curing which leads to war page.

• Parts can be quite brittle.

• Support structures are required.

• Uncured material can be toxic

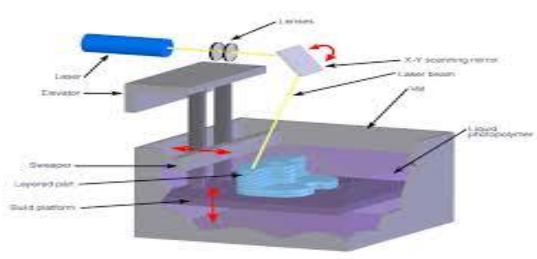


Figure 1.12 Stereo lithographgy

3.4.2 Selective laser sintering

Selective laser sintering (SLS) is another additive prototyping process that builds parts by sintering powdered materials by a laser, layer by layer, from the bottom up. This technology was developed by Carl Deckard at the University of Texas at Austin, and subsequently patented by him in 1989.Sintering is a fusion process at a temperature above one-half the material melting temperature, but below the melting temperature. Sintering welds two or more particles together and consolidates them into a solid part, usually under pressure

A layer of powder (particle size approximately 50 µm) is spread over a platform and heated to a temperature just below the melting temperature. A carbon dioxide laser needs to raise the temperature only slightly and selectively to melt the powder particles. As the layer is finished, the platform moves down by the thickness of one layer (approximately 0.10–0.15 mm), and new powder is spread. When the laser exposes the new layer, it melts and bonds to the previous layer. The process repeats until the part is complete.

Characteristics

- Key advantage of making functional parts in essentially final materials.
- Good mechanical properties, though depends on building orientation.
- Powdery surface
- Many variables to control
- No support required

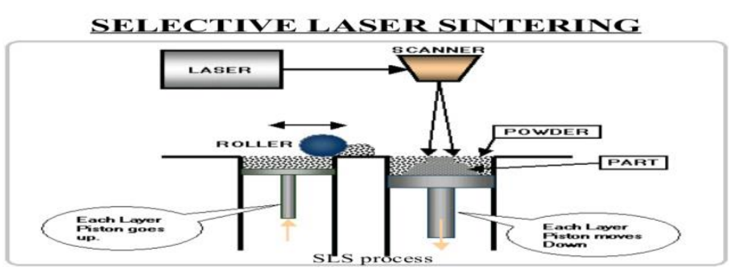


Figure 1.13 Selective laser sintered

3.4.3 Fused Deposition Modeling

Fused deposition modeling (FDM), developed by Stratasys, is also an additive process. It is a very popular rapid prototyping technology and is widely used, only second to SLA

It builds parts from the bottom up through a computer-controlled print head. In contrast to SLA, whereby a liquid resin pool is used, and SLS, whereby the compacted resin powders are used, the feedstock for FDM is a filament of extruded resin that remelts and deposits on top of the previously formed layers. The FDM process utilizes a variety of polymeric materials, including acrylonitrile butadiene styrene (ABS), polycarbonate, and polyphenylsulfone. The ceramic and metallic materials are also potential candidate materials that can be used in the FDM process in the future. The FDM parts are relatively strong with good bonding between the layers, and can be used for functional tests in reverse engineering when appropriate. However, the FDM parts are often porous, with a rough surface finish, and of relatively poor tolerance control

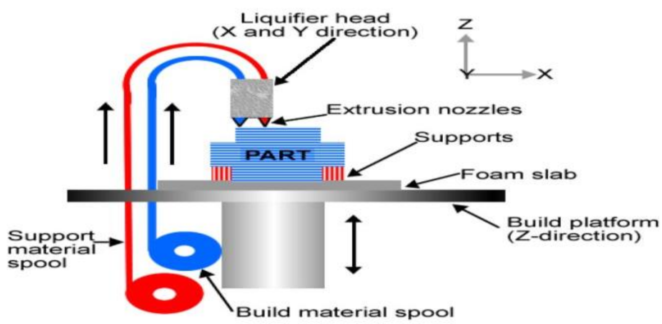


Figure 1.14 Fused deposition system

Characteristics

• Office-friendly and quiet.

• FDM is fairly fast for small parts.

• Good mechanical properties, so suitable for producing functional parts.

• Wide range of materials.

3.4.4 Three-dimensional Printing

In this process, a layer of powder is spread over a platform. The particles are bonded together selectively by a liquid adhesive (binder solution). This liquid is deposited in a two-dimensional pattern by a multichannel jetting head. As the current layer is completed, the platform moves down by the thickness of a layer, so that a new layer can be spread. This process is repeated until the entire object is formed within the powder bed. On completion, the object is elevated and the extra powder is brushed away, leaving a fragile "green" object. It is necessary to infiltrate the part with another material to improve mechanical characteristics.

No support structures are required because the surrounding powder particles support overhanging features. By adding color to the binder solution, objects can be produced in every desired color. Starch, plaster, medicines (for producing controlled-dosage pharmaceuticals), ceramics, and metals are commonly used materials (powders) for 3-DP.

Characteristics

• Limitations on resolution and surface finish.

• Fragile objects need to be infiltrated.

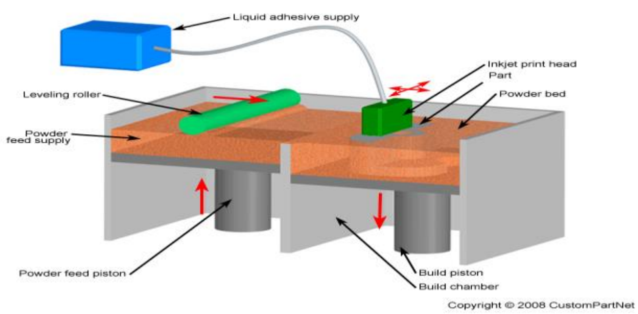


Figure 1.15 Three dimensional printing method

3.4.5: Laminated Object Manufacturing

In laminated object manufacturing (LOM), a sheet of paper (unwound from a feed roll) with a polyethylene coating on the reverse side is placed on a platform. This coating is melted by a heated roller, making the paper adhere to the platform. Then, a carbon dioxide laser cuts out the cross -section of the object and a border. The laser also creates hatch marks, or cubes that surround the pattern within the border. These cubes behave as a support structure for the model. When the laser has finished the layer, a new paper sheet is applied.

Upon completion, the model is captured within a block of paper. When all of the surrounding cubes have been removed, the unfinished part is sanded down. The humidity and temperature dependency of the paper material can be reduced by coating the model. The finish and accuracy are not as good as with some other methods; however, objects have the look and feel of wood and can be worked and finished like wood.

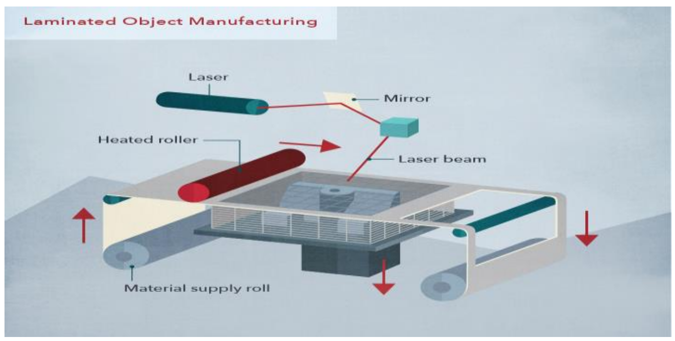


Figure 1.16 Laminated object manufacturing

3.4.6: Multijet Modeling

Multijet modeling (MJM) uses multiple print heads to deposit droplets of material in successive, thin layers. A 96-element print head deposits droplets of wax. Because of its relatively fast production, this technique is marketed to the engineering or design office for quick form studies (concept modeling). However, wax models can also be used as master patterns for investment casting.

A print head jets two separate materials, an acrylic UV-curable photopolymer-based model material and a wax-like material to produce support structures for the model. Due to the relative good quality of the models, production speed, and surface finish, applications range from preliminary prototypes to mock-ups for concept proposal or marketing models.

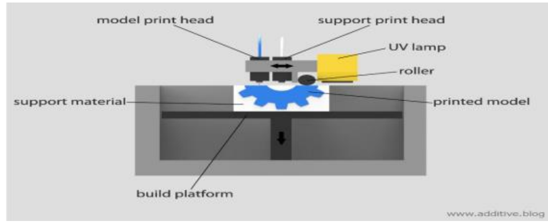


Figure 1.17 Multijet modeling

3.4.7: Laser-engineered Net Shaping

In laser-engineered net shaping (LENS), a laser beam focuses onto a metal substrate to melt the upper surface. A deposition head then applies metal (powder or fine wire) into the molten puddle to increase the material volume. By moving the platform in raster fashion, each layer of the object is fabricated. An inert gas is used to shield the melt puddle from atmospheric oxygen for better control of properties and to promote layer-to-layer adhesion by providing better surface wetting.

Fully dense metal parts (made of stainless steel, aluminum, copper, Inconel, titanium, etc.) can be produced by LENS. It is even possible to change the material composition dynamically, which lead to objects with properties that might mutually exclusive using traditional fabrication methods. Although produced parts are near net shape, they generally require post processing. Applications of LENS are injection molding tools and aerospace parts.

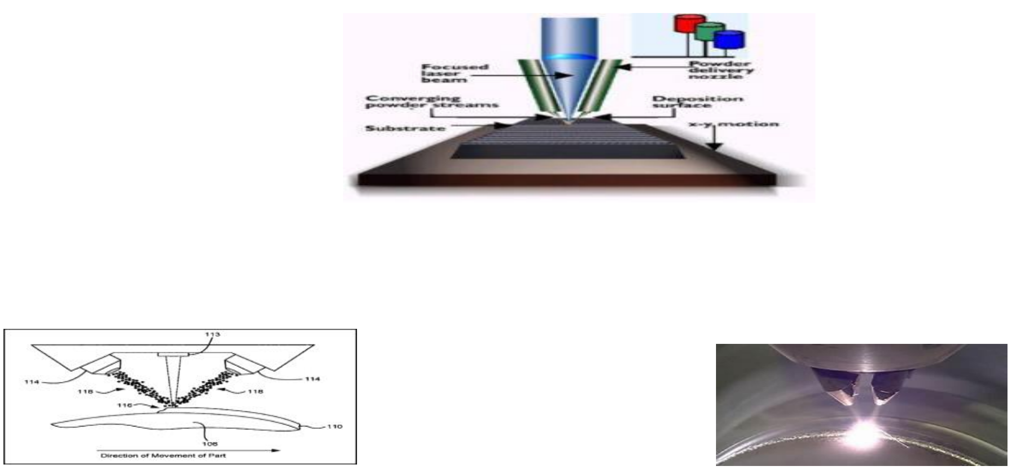


Figure 1.18 Laser engineered net shaping

3.5 Merits of additive prototyping

- **Freedom of design** The production of complex parts is reduced to the accumulation of layers.
- **Well automated** No supervision is needed during the build process.
- **Relative easy to employ** Only little preparation and post processing are required.
- Avoiding the high cost of prototype tooling, allowing (more) design iterations.
- Physical models are easy to check for errors.
- It can create parts with complicated internal features that are difficult to manufacture.

3.6 Demerits of additive prototyping

- Accuracy generally >0.1 mm.
- **Material properties** Products can be very fragile, and some need post processing before they can be handled (as with 3-DP).
- **Stair casing effect** Because an inclined surface is constructed using several layers, stair casing will occur.
- Most additive prototyping technologies do not provide any information
  On part machinability and manufacturability of the design.
- The additive prototyping technologies are also subject to some other restrictions, such as part size, applicable material, and limited production.
- Metal prototypes are noticeably difficult to make with the additive prototyping process.

3.7 Application of additive prototyping

Aerospace

NASA engineers drew on ingenuity and advanced technology. About 70 of the parts that make up the rover were built digitally, directly from computer designs, in the heated chamber of a production-grade Stratasys 3D Printer. The process, called Fused Deposition Modeling (FDM) Technology or additive manufacturing, creates complex shapes durable enough for Martian terrain [7].For its 3D-printed parts, NASA uses ABS, PCABS and polycarbonate materials. FDM, patented by Stratasys, is the only 3D-printing method that supports production-grade thermoplastics, which are lightweight but durable enough for rugged end-use parts.

Health

While much effort is put forth by individuals, societies, and businesses to improve our physical health, an ideal health is very subjective and could depend on location and vary over time. However, it can be said that the absence of sickness, specially, chronic illnesses is a requisite for good health. Illnesses, accidents, and aging deteriorate the body's or a specific organ's condition. Organ transplants have been successfully conducted for the past century; however, there has always been a shortage of donors or an inability to find a match between the donor and recipient in time. 3D printing is an advanced recent technology in this field which can be a revolutionary alternative with a variety of applications in the transplant and healthcare industry in general. 3D printing research is investigated in various fields within the healthcare industry; some of which are discussed in this section.

Architecture industry

Poly-Jet 3D printing technology produces astonishingly smooth, detailed architectural models in an array of materials, including rigid photopolymers ready for painting. For models that must bear loads or take abuse, FDM Technology builds strong parts in production-grade thermoplastics.

Dental implants

Dental industry has been using artificial material for dentures, orthodontics, implants, crown, and bridges for many years. As these parts are custom made for each person, the process is both time consuming and expensive. Direct and indirect 3D printing, namely printing the actual part or a mold, has been shown to be a cheaper and faster alternative to conventional technique.

Skull and jaw implant

Researchers have shown that 3D printed parts can be used as bone replacement for people whom lost part of their skull or jaw in an accident.

Automobile industry

One of Ducati's key challenges is to reduce time-to-market for new products by reducing the design cycle. To help meet this challenge, the entire design process is validated using FDM prototyping systems from Fortus. FDM (fused deposition modeling) enables Ducati to build both concept models and functional prototypes from ABS, polycarbonate and poly-phenylsulfone.

Jigs and Fixtures

Inkjet-based technology and FDM Technology, both available from Stratasys, provide fast and accurate methods to produce and manufacture tools. 3D printing jigs and fixtures with inkjet or FDM can help reduce the backlog for an in-house machine shop and be used as a bridge-to-tooling solution.

Education

The education system plays an important role in aiding people achieve their full potential. 3D printing can revolutionize the learning experience by helping students interact with the subject matter. Affordable 3D printers in schools may be used for a variety of applications which can aid students in finding their field of interest easier and faster. Currently there are different types of educational projects in order to attract students to the various fields by giving them the opportunity to create and fabricate their own designs using 3D printing technology.

Chapter-II

Literature review

Every research is undertaken by doing a thorough review of the development and research work undertaken in the specific area/domain of the given research work. In a to do justice to the given proposed work to be get a better insight, the following literature is carried out for the analysis of the existing system working and also critically evaluated, to find if there are any shortcomings.

A substantial research is carried out in these fields by researchers. This part of study enlightens briefly on some of work done by those researchers. The work from various books, papers, articles, journals has been referred for this purpose it is humble approach to thank those researchers whose work done will be referred in this research. Some of them are mentioned in the article.

Reverse engineering

A. Kumar et.al. (2014) [1] provided a technique for measurement and inspection of machine element using reverse engineering tool. Their study uses a spur gear which wears out during operation due to friction. The methodology includes scanning of worn out spur gear to obtain the point data, generation of surfaces and creating a 3D model, and final step is comparing the two model i.e. model obtained after scanning of worn out part to that of obtained from actual gear tooth profile so that worn area can be recognized and further action of maintenance can be applied.

H. Wu et.al. (2013) [2] have reviewed several algorithms based on geometric reconstruction and repairing methodologies for gas turbine component which is a critical component because of its complexity in shape and high cost of repair. The paper includes different types of algorithms for the repairing solutions of damaged blades. The process of repair and overhaul is a five stage process: pre repair inspection, identification, surface reconstruction of defected surface, welding, milling and grinding. They also concluded that available reconstructing approaches are not efficient so future work is required in this field.

Bhupender Singh et. al. (2011) [3] presented the solid modeling and finite element analysis of crane boom using PRO/E WILDFIRE 2.0 and ALTAIR HYPER MESH with optistruct 8.0 solver Software to get the variation of stress and displacement in the various parts of the crane boom and possible actions were taken to avoid the high stress level and displacement. The solid model was created using pro/E Wildfire 2.0 using given dimensions. Then the solid model was imported to ALTAIR HYPER MESH and analysis of the model was carried out in OPTISTRUCT SOLVER 8.0 under given constraints. The stress values calculated for three load points were found to be under the limits of ultimate tensile strength and yield strength of boom material. So it can be said that under the given conditions of boom material and load carrying capacity, crane boom was safe to lift the load up to 12 Tonne

E. Bagci (2009) [4] defined the reverse engineering process as the five stage process which includes digitization, data capturing, processing phase, surface approximation (for solid modeling), technical documentation and, NC part programming and CNC milling machine (for the part manufacturing) using three samples which were broken and worn in some regions. Components used for study are damaged cam-worn due to friction, turbine blade and a defected Ataturk’s bust. These components were recreated using RE and modifications have been made to them in order to recover their final geometry. After recovery CAD models were used for part manufacturing using a CNC milling machine.

M. Manzoor Hussain et. al. (2008) [5] presented the development of computer technology resulted in the integration of design and manufacturing systems and automated inspection/gauging systems in manufacturing engineering applications. Geometrical information of a product was obtained directly from a physical shape by a digitizing device, from this complete 5-axis tool path was obtained. Duplicating the part was done with the help of CMM and CAD/CAM software like Mastercam, ProEngineer etc. CMM was used to digitize the mechanical object. Taking coordinates (scan data) of the various points on the surface of the object and converting it into IGES file and using the same in the CAD/CAM software with required interfacing created a surface or solid model of the object. Finally this solid model was used to generate CNC part program to manufacture the part on CNC Machining center.

Lin et al. (2005) [6] had presented the measure method to get the better data points and the appropriate method to deal with points cloud data. Reverse engineering software was then used to create the free-form surfaces from the point cloud data.

Rapid prototyping

3D printing was known as “rapid prototyping”. Chuck Hull, of 3D Systems Corporation, created the first working 3D printer in 1984 [7]. Later in the 80’s, Selective Laser Sintering (SLS) technology was developed by Dr. Deckard at the University of Texas at Austin during a project sponsored by Defense Advanced Research Projects Agency (DARPA). In the 1990s, the technology was further improved with the development of a method that used ultraviolet light to solidify photopolymer, a viscous liquid material.

D.A. Roberson et al. [8] evaluated the capability of five desktop additive manufacturing (AM) machines based on the ability to produce a standard component. This work also developed a model/method for evaluating and ranking AM technologies based on select criteria that can facilitate purchasing decisions. A standard part was designed and printed on each machine, and evaluated based on dimensional accuracy and surface finish. Additionally, the machines were compared based on build time for single and multiple parts as well as material consumption and unit cost. The ranking system presented in this paper has demonstrated the ability to discriminate between different AM processes and rank these systems based on quantitative measures.

Lee and Kim [9] analyzed the trend of 3D printing-related patents for the last 10 years to investigate patent application trends by country, by year, by assignee and by technology. Furthermore, the paper analyzed the patent trend on 3D printers and materials used to secure original technologies and a portfolio of application technologies in medium and long terms.

Berman [10] in his paper examined the characteristics and applications of 3D printing for mass customization. He argued that there are a number of promising applications exist in the production of replacement parts, dental crowns, and artificial limbs, as well as in bridge manufacturing. 3D printing market allow firms to profitably serve small market segments, and enable companies to operate with little or no inventory and significantly reduce the need for factory workers.

Huang [11]et al. reviewed the societal impact of additive manufacturing in (1) customized healthcare products to improve population health and quality of life, (2) reduced environmental impact for manufacturing sustainability, and (3) simplified supply chain to increase efficiency and responsiveness in demand fulfillment. Their review also identified the need for further research in the areas of life-cycle energy consumption evaluation and potential occupation hazard assessment for additive manufacturing.

Chapter-III

Methodology and material study

1 Study of model

The present study is based on the reconstruction of the foot valve mesh that is used for the suction of the underground water and to control the reverse flow of the water due to gravity. The component which we see in the Figure 3.1 is corroded due to which capturing of its original dimension is difficult task for us, more over the component was also damaged.

Figure 3.1 Assembly of foot valve mesh

2 Methodology

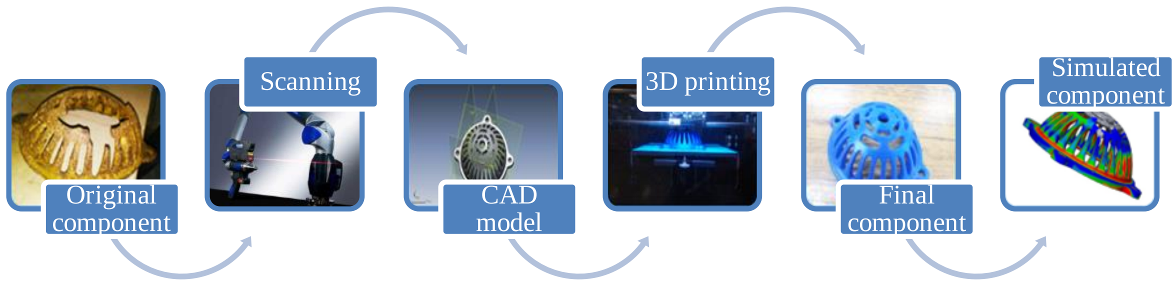


Figure 3.2 Process performed

In first stage of operation original component selected is scanned by using laser scanning to get point cloud which is triangulated and saved in .STL format. The file was imported in the reverse engineering software where the remodelling of the component and conversion into CAD format was done sent to the additive prototyping (3D printing) Machine. Here the plastic 3D printed part is fabricated then finally compared with the

Original one.

2.1 Acquisition of raw point clouds data

Digitization of the model was made with an active non-contact scanning process using a portable laser scanner (Shining 3D EinScan-Pro) is shown in Figure below. The acquisition system of points was controlled automatically by software of equipment (EINSCAN-S). 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.

2.1.1 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.

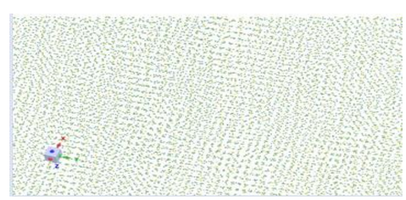
2.1.2 Noise reduction

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.

2.1.3 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 center of each grid is retained as shown in the Figure 6.3.

(a)



(b)

Figure 3.3 Point cloud data a) with sampling. b) Without sampling

2.1.4 Wrapping

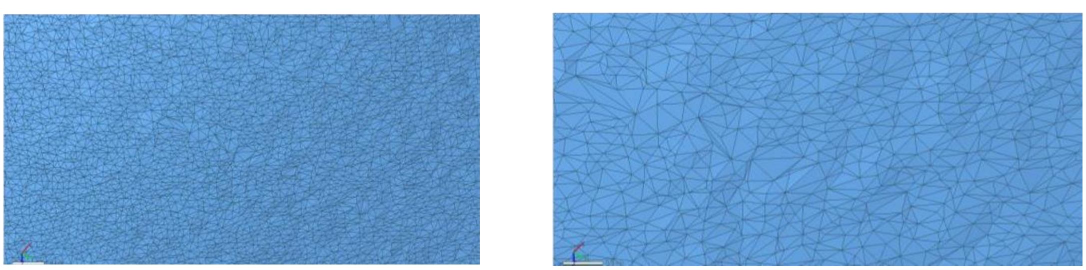
Wrapping is a process of converting a point object to a polygon object. It is advantageous to wrap a point object because there are many refinements that can be performed on a polygon object that cannot be performed on a point object. The method works by maintaining a list of points from which the mesh can be grown and extending it until all possible points are connected. 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 neighborhood of a point along its normal connecting the unconnected points.

2.1.5 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.

2.1.6 Simplifying Model (Reducing Triangles)

'Simplify' allows reducing the number of triangles as shown in figure 3.4 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 3.4 Meshing a) without simplifying b) with simplifying

2.17 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.

- **Curvature Fill** Specifies that the new mesh that fills the selected holes must match the curvature of the surrounding mesh.
- **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.
- **Flat Fill** Specifies that the new mesh that fills the selected holes is generally flat.

2.2 Component description

A damaged foot valve mesh is selected for the project of reverse engineering which is in the figure 3.5. The component has been corroded and having few broken parts. Recovering of the dimensions is difficult. This part is used for filtering water during suction which is assembled with foot valve for lifting of water with the help of motor from ground level. The objective of selecting this component is to learn how to design and reconstruct of such damaged and broken parts with the help of reverse engineering software.

Figure 3.5 original component

2.3 Data scanning

A Point Cloud data which is in the .ase format meshed and it is saved in .stl format as shown in the figure 3.6. This process generates mesh type of faceted triangular surface. This surface is not a CAD surface and still needs to be converted which is in the form of a solid model.

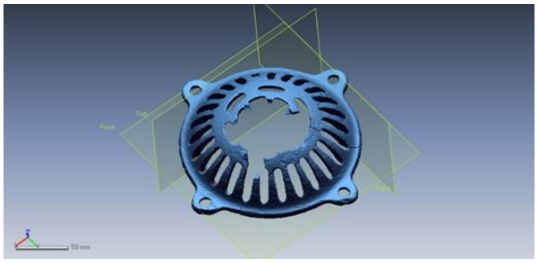


Figure 3.6 Mesh STL format

Steps in conversion

- Triangulate Tool: It is used for converting a point cloud into a mesh object.
- Mesh Construction: Used for meshing and merging of multiple meshes.
- Healing Wizard and Fill Holes tool: As the Name suggests it is used for Hole filling and healing defects

2.4 Modeling

The mesh .stl file is then imported in the reverse engineering software there using the modeling tools such as extrude, surface revolve, circular pattern, bolean the component was remodeled. The restored model as shown in the figure 3.7 is converted into the CAD file format which is extreme file is sent to the 3d printing machine, now the part is ready to undergo additive prototyping process.

Figure 3.7 Remodeled CAD format component

2.5 Additive prototyping

The additive prototyping machine named Trovole FDM dual extruder 3D printer is used for printing the component. The CAD format file which is sent to the 3D printing machine is stored. Here the PLA (polylactic acid) filament that is in the form of wire of diameter 1.75mm is wound around the spool and installed in the machine. PLA filament is widely thought of as an aesthetic material best used for prototyping. Hence the PLA filament melts at temperature limit of 180 ° - 230 ° and generates the prototype by adding layer by layer with a time lapse 5h 25m as shown in the figure 3.8.

2.5 Material properties of PLA

- **Strength:** High/ **flexibility** low/ **durability** medium.
- **Difficulty to use** Low
- **Print temperature** 180 ° - 230 °
- **Print bed temperature** 20° - 60° (but not needed)
- **Shrinkage/ wrapping** Minimal
- **Soluble** No

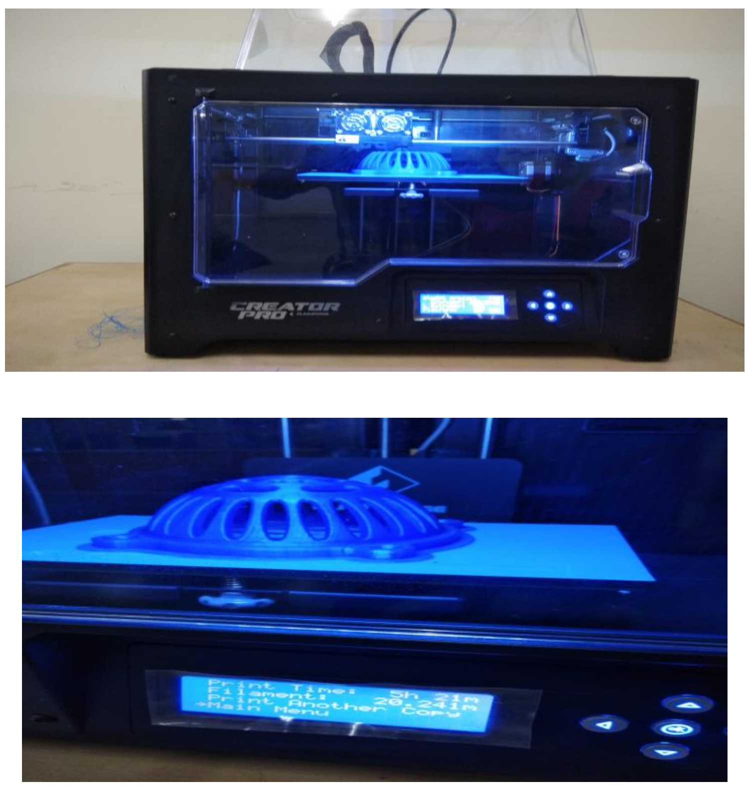
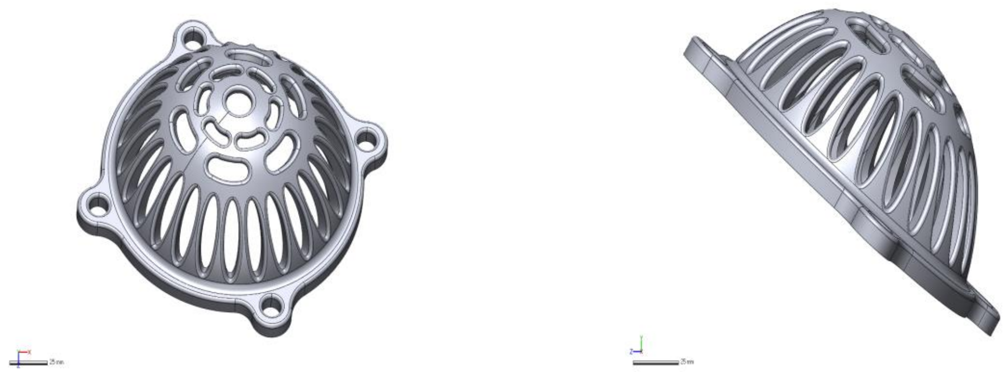


Figure 3.8 3D printed prototype

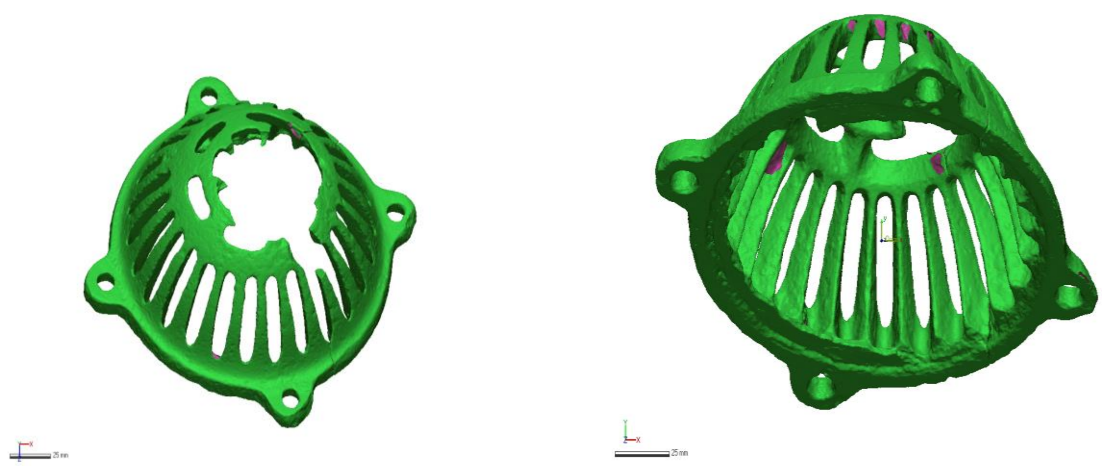
Chapter-IV

Results and discussion

The reference part as shown in figure 4.1 (a) in comparison with CAD model as shown in figure 4.1 (b) is aligned together to assess the deviation in order to ensure the manufacturability of the part earlier in the design phase.



(a)

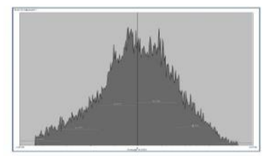


(b)

Figure 4.1 (a) CAD model (b) Original

The alignment that is preferred for the comparison of the part are shown in figure 4.2

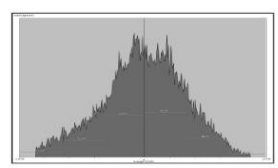
Result Data - 1 : Best Fit Alignment1



Min.	-2.2617
Max.	2.2615
Avg.	0.0103
RMS	0.8699
Std. Dev.	0.8698
Var.	0.7566
+Avg.	0.6865
-Avg.	-0.7077

Product Name	[Product Name]	Department	[Department]	Date	Apr 16, 2019
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 : Initial Alignment1

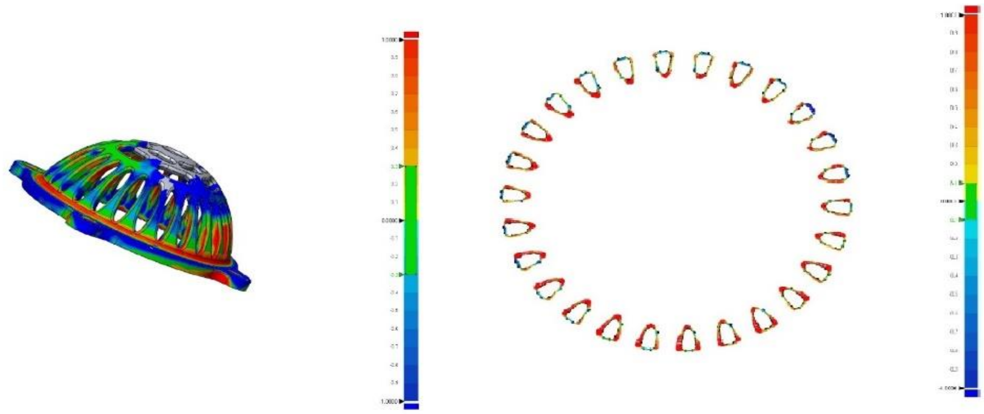


Min.	-2.2617
Max.	2.2615
Avg.	0.0103
RMS	0.8699
Std. Dev.	0.8698
Var.	0.7566
+Avg.	0.6865
-Avg.	-0.7077

Product Name	[Product Name]	Department	[Department]	Date	Apr 16, 2019
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Figure 4.2 Best fit and initial alignment

The maximum deviation we got for best fit and initial fit alignment is -2.2617 and minimum deviation is 2.2615. Also showing the same standard deviation of 0.8699.



Min.	-7.1586
Max.	7.1505
Avg.	-0.3196
RMS	1.5462
Std. Dev.	1.5128
Var.	2.2885
+Avg.	0.7466
-Avg.	-1.2649
In Tol.(%)	24.0906
Out Tol.(%)	75.9094
Over Tol.(%)	35.4452
Under Tol.(%)	40.4642

Min.	-2.6644
Max.	2.1289
Avg.	0.6097
RMS	0.8599
Std. Dev.	0.6064
Var.	0.3677
+Avg.	0.78
-Avg.	-0.3246
In Tol.(%)	7.3457
Out Tol.(%)	92.6543
Over Tol.(%)	80.0982
Under Tol.(%)	12.5561

Figure 4.3 3D and 2D comparison

Here the comparison is done for both 3D and 2D, Units are in “mm “and the deformation in the material is shown with the colour indicated in figure 4.3. The red colour indicates The Maximum deviation and blue colour indicates the minimum deviation. The maximum and minimum deviation in 3D compare is ±7.1505mm and standard deviation as

1.5128mm. where as in 2D compare the maximum and minimum deviation is ±2.6644 while standard deviation is 0.6064.In case of 3d compare the initial tolerance is 24.0906% and outer tolerance is 75.9094% and for 2D compare the inner tolerance is 7.3457% whereas outer tolerance 92.6543%.When compared to the original CAD file 40.4642% under tolerance and over tolerance 35.445% In 3D compare, For 2D the under tolerance is 12.5561% and over tolerance is 80.0982%.

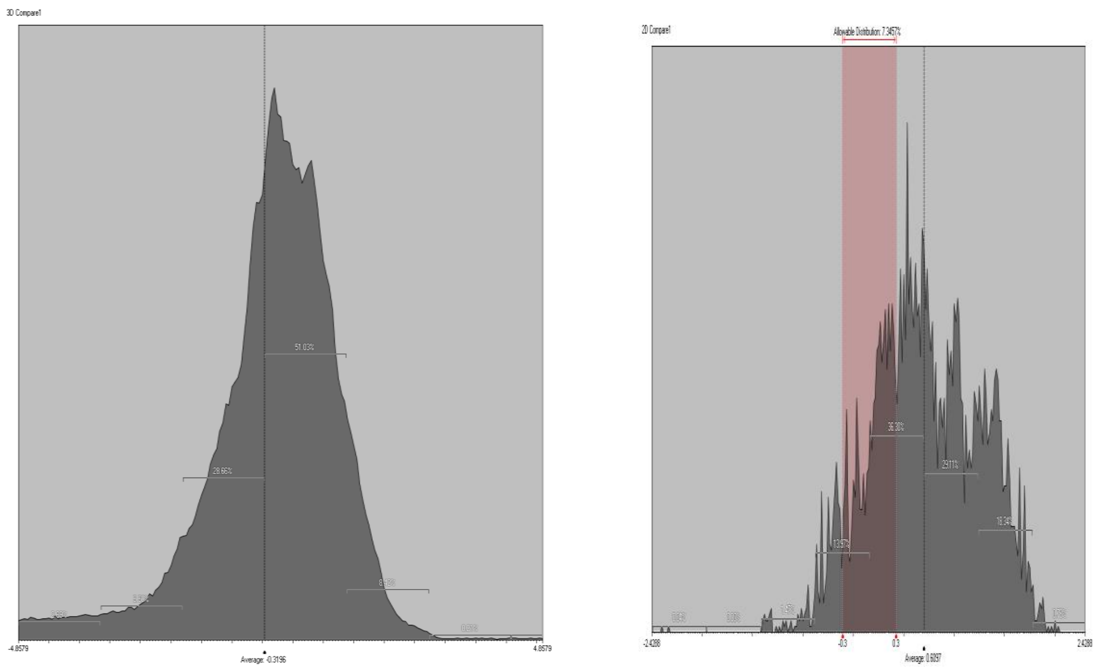


Figure 4.4 Deviation distribution curve of 3D and 2D compare

The deviation distribution curve as shown in figure 4.4 gives the average value of distribution +0.7466 and -1.2649 for 3D where as +0.78 and -0.3246 for 2D. Finally the deviation we got in both 3D and 2D compare is ±1 which is negligible and can be recommended for manufacturing.

Chapter-V

Conclusion

Conclusion

In adoption to new technologies for optimizing the production cost of industry these reverse engineering and additive prototyping method will be the best preferred approach. As it need not have to move towards formal way of designing from initial which is the difficult task, but to have the old one which had its own data acquired in software from which one can reconstruct easily using the modeling tools. These report gives the clear idea how the reverse engineering is used step by step. It also gives the information about the scanning method and performance. By utilizing the reverse engineering software also makes the reader learning the construction tools that are going to be applied. In addition, it also gives the knowledge of file format used for the reverse engineering and additive protyping. However, in many instances, it may lose small details if it goes directly into a STL file.

The 3D printed part and the original part was compared in order to check whether there is any dimensional errors that is to be notice. Both technologies are thus linked together that makes benefit not only to a manufacturing industry but also pharma, medical etc many more. Arranging the point cloud data automatically during scanning and printing by high alloy steel is recommend for future work.

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A PROJECT REPORT

ON

Restoration of damaged component using Reverse Engineering and Rapid prototyping

Submitted for partial fulfillment of the requirements for the award of the degree

Of

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

RAVI CHANDRA NAIK (15911A03A3)
JAINIL SAVLA (15911A0374)
G. VARUN TEJ (15911A0372)
C. KARTHIK (15911A0364)

Under the guidance of
Dr. G. Sreeram Reddy
Professor
Department of Mechanical Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

(Autonomous)

AZIZNAGAR, CHILKUR ROAD, HYDERABAD-**500075**

CERTIFICATE

This is to certify that the project work entitled "**Restoration of damaged component using Reverse Engineering and Additive prototyping**" is a bonafide project work submitted by **RAVI CHANDRA NAIK (15911A03A3), JAINIL SAVLA (15911A0374) G.VARUN TEJ (15911A0372) C. KARTHIK (15911A0364)** in partial fulfillment of requirements for the award of degree of **Bachelor of Technology in Mechanical Engineering** by the **JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY,** Hyderabad, under our guidance and supervision.

The results embodied in this report have not been submitted to any other university or institute for the award of any degree or diploma.

INTERNAL GUIDE
Dr. G. Sreeram Reddy
Professor
Department of Mechanical
Engineering, VJIT, Hyderabad.

HEAD OF DEPERMENT
Dr. G. Sreeram Reddy
Department of Mechanical
Engineering, VJIT, Hyderabad.

17/5/19

External Examiner

DECLARATION

This is to certify that the work reported in the present project entitled "Restoration of damaged component using Reverse engineering and Additive prototyping" is a record of work done by us in the Department of MECHANICAL ENGINEERING, Vidya Jyothi Institute of Technology (Autonomous), Jawaharlal Nehru Technological University, Hyderabad. The reports are based on the project work done entirely by us and not copied from any other source.

Ravi Chandra naik

Jainil Savla

G.Varun Tej

C. Karthik

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Abstract

This present project gives a compilation of work related to reconstruction of a damaged "FOOT VALVE MESH" utilizing the reverse engineering process to scan and transfer the geometry of part into a useful 3D dimensional model that can be sent to 3D printer and turned into an actual physical part. Also the computer model is converted to 3D computed aided design (CAD) model to perform the alignment test and validate the liability of the part in the real world condition. The process includes the utilizing of faro arm laser scanning, reverse engineering software, 3D printer.

The Laser scanner and reverse engineering creates a 3D model of the part which is used as basic model for the manufacturing process in addition the 3D printer is utilized to create a prototype of the part to ensure the manufacturability of the part early in design phase. Furthermore simulation software is used for performing alignment and making recommendation to improve the liability of the part. The deviation are assessed by 2D and 3D comparison to domain of the part can be properly handled in real time circumstances. Finally under tolerances among the 3D and 2D compare values obtained are minimum.

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CHAPTER-I

INTRODUCTION

In today's considerably growing competitive global market, product enterprises are constantly seeking new ways to shorten lead times for new product developments that meet all customer expectations. Engineering fields are constantly improving upon current designs and methods to make life simple and easier. When referring to technology, simple and easy can be directly related to fast and accurate.

This Thesis describes a complete prototyping process using the Reverse Engineering techniques. The geometry of a mechanical component is captured using digitizing arm and Reverse Engineering (RE) software. The Rapid prototyping process used is Fused Deposition Modeling (FDM) system. It also describes the step-by-step procedure for making the prototype as well as the hardware and software used for making the prototype model.

When we think of engineering we think of the general meaning of designing a product from a blue print or plan. Engineering is described as "the application of scientific and mathematical principles to practical ends such as the design, manufacture, and operation of efficient and economical structures, machines, processes, and systems". This type of engineering is more commonly known as Forward Engineering. An emerging engineering concept is utilizing forward engineering in a reverse way. This method is more commonly referred to as Reverse Engineering.

Reverse engineering is the opposite of forward engineering. It is the process of analyzing a subject system to create representations of the system at a higher level of abstraction. It can also be seen as going backwards through the development cycle. Reverse engineering is taking apart an object to see how it works in order to duplicate or enhance the object. It takes an existing product, and creates a CAD model, for modification or reproduction to the design aspect of the product.

With this knowledge, computer vision applications have been tailor to compete in the area of reverse engineering. Computer vision is a computer process concerned with artificial intelligence and image processing of real world images. Typically, computer vision requires a combination of low-level image processing to enhance the image quality (e.g. remove noise, increase contrast) and higher level pattern recognition and image understanding to recognize features present in the image. Three-dimensional (3D) computer vision uses two-dimensional (2D), images to generate a 3D model of a scene or object.

The impact of reverse engineering plays a significant role in promoting industrial evolution. The life cycle of a new invention usually lasted for centuries in ancient times. It took thousands of years to invent the electric light bulb for the replacement of the lantern. Both industry and society accepted this slow pace. However, the average life cycle of modern inventions is much shorter. It has only taken a few decades for the invention of the digital camera to replace the film camera and instant camera. This has led to a swift evolution of the photo industry.

In general, product enterprise has invested in CAD/CAM, rapid prototyping, and a range of new technologies that provide business benefits. Reverse engineering (RE) is now considered one of the technologies that provide business benefits in shortening the product development cycle. Figure 1.1 below depicts how RE allows the possibilities of closing the loop between what is "as designed" and what is "actually manufactured".

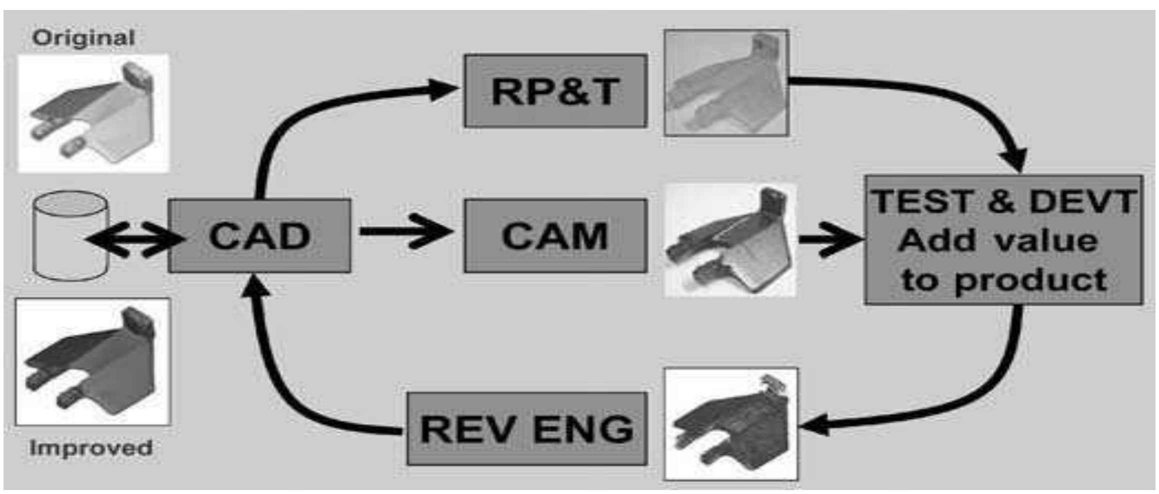


Figure 1.1 Product development cycle

1 Reverse engineering

1.1 Introduction

Reverse engineering (RE) is a process of measuring, analyzing, and testing to reconstruct the mirror image of an object or retrieve a past event. It is a technology of reinvention, a road map leading to reconstruction and reproduction. It is also the art of applied science for preservation of the design intent of the original part.

Reverse engineering can be applied to re-create either the high-value commercial parts for business profits or the valueless legacy parts for historical restoration. To accomplish this task, the engineer needs an understanding of the functionality of the original part and the skills to replicate its characteristic details. Though it roots back to ancient times in history, the recent advancement in reverse engineering has elevated this technology to one of the primary methodologies utilized in many industries, including aerospace, automotive, consumer electronics, medical device, sports equipment, toy, and jewelry. It is also applied in forensic science and accident investigations. Manufacturers all over the world have practiced reverse engineering in their product development. The new analytical technologies, such as three-dimensional (3D) laser scanning and high-resolution microscopy, have made reverse engineering easier, but there is still much more to be learned.

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.

Reverse engineering provides a solution to this problem because the physical model is the source of information for the CAD model. This is also referred to as the physical-to-digital process. Another reason for reverse engineering is to compress product development cycle times. In the intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead times to market a new product. Rapid product development

(RPD) refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of shortened product development time. For example, injection-molding companies need to shorten tool and die development time drastically. By using reverse engineering, a three-dimensional physical product or clay mock-up can be quickly captured in the digital form, remodeled, and exported for rapid prototyping/tooling or rapid manufacturing using multi-axis CNC machining techniques.

1.2 Reverse Engineering–The Generic Process

The generic process of reverse engineering is a three-phase process as depicted in Figure 1.2. The three phases are scanning, point processing, and application specific geometric model development. Reverse engineering strategy must consider the following:

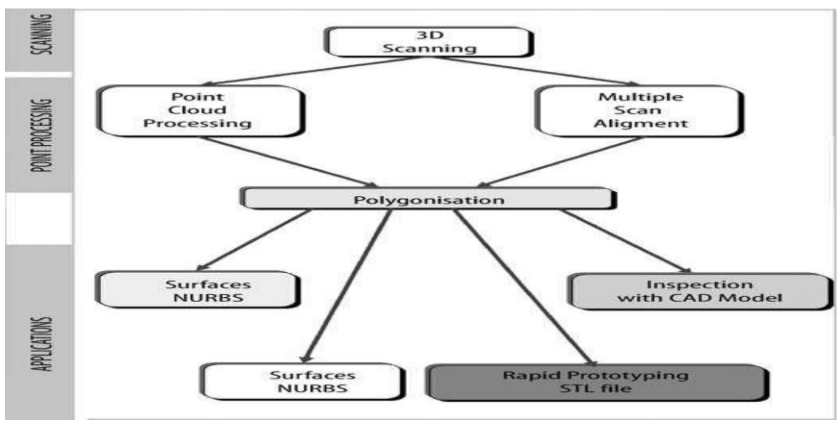


Figure 1.2 Reverse engineering – the generic process

• Reason for reverse engineering a part

• Number of parts to be scanned–single or multiple

• Part size–large or small

• Part complexity–simple or complex

• Part material–hard or soft

• Part finish–shiny or dull

• Part geometry–organic or prismatic and internal or external

• Accuracy required–linear or volumetric

1.2.1 Phase 1–Scanning instrument and technology

One of the biggest challenges of reconstructing a mechanical part is to capture its geometric details. Fortunately, advanced devices have been developed to image the three-dimensional features of a physical object and translate them into a 3D model with high accuracy. Data can be obtained directly using a digitizer that is connected to a computer installed with reverse engineering software. The two most commonly used digitizing devices are probes and scanners.

This phase is involved with the scanning strategy–selecting the correct scanning technique, preparing the part to be scanned, and performing the actual scanning to capture information that describes all geometric features of the part such as steps, slots, pockets, and holes. Three-dimensional scanners are employed to scan the part geometry, producing clouds of points, which define the surface geometry. These scanning devices are available as dedicated tools or as add-ons to the existing computer numerically controlled (CNC) machine tools.

1.2.2 Phase 2–Point Processing

This phase involves importing the point cloud data, reducing the noise in the data collected, and reducing the number of points. These tasks are performed using a range of predefined filters. It is extremely important that the users have very good understanding of the filter algorithms so that they know which filter is the most appropriate for each task. This phase also allows us to merge multiple scan data sets. Sometimes, it is necessary to take multiple scans of the part to ensure that all required features have been scanned. This involves rotating the part; hence each scan datum becomes very crucial. Multiple scan planning has direct impact on the point processing phase. Good datum planning for multiple scanning will reduce the effort required in the point processing phase and also avoid introduction of errors from merging multiple scan data. A wide range of commercial software is available for point processing.

The output of the point processing phase is a clean, merged, point cloud data set in the most convenient format. This phase also supports most of the proprietary formats mentioned above in the scanning phase.

1.2.3 Phase 3–Application Geometric Model Development

In the same way that developments in rapid prototyping and tooling technologies are helping to shorten dramatically the time taken to generate physical representations from CAD models, current RE technologies are helping to reduce the time to create electronic CAD models from existing physical representations.

The need to generate CAD information from physical components will be arise frequently throughout any product introduction process.

The generation of CAD models from point data is probably the most complex activity within RE because potent surface fitting algorithms are required to generate surfaces that accurately represent the three-dimensional information described within the point cloud data sets. Most CAD systems are not designed to display and process large amounts of point data; as a result new RE modules or discrete software packages are generally needed for point processing. Generating surface data from point cloud data sets is still a very subjective process, although feature-based algorithms are beginning to emerge that will enable engineers to interact with the point cloud data to produce complete solid models for current CAD environments.

The applications of RE for generating CAD data are equally as important as the technology which supports it. A manager’s decision to employ RE technologies should be based on specific business needs. This phase depends very much on the real purpose for reverse engineering. For example, if we scanned a broken injection molding tool to produce a new tool, we would be interested in the geometric model and also in the ISO G code data that can be used to produce a replacement tool in the shortest possible time using a multi-axis CNC machine. One can also use reverse engineering to analyze “as designed” to “as manufactured”. This involves importing the as designed CAD model and superimposing the scanned point cloud data set of the manufactured part. The RE software allows the user to compare the two data sets (as designed to as manufactured). This process is also used for inspecting manufactured parts. Reverse engineering can also be used to scan existing hip joints and to design new artificial hips joint around patient- specific pelvic data. This creates the opportunity for customized artificial joints for each patient. 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.

1.3 Merits of reverse engineering

- It helps in the evolving of existing computing systems.
- You can change a programs structure and thus directly affects its logical flow. Technically this activity is called patching, because it involves placing new code patches (in a seamless manner) over the original code.

- Can be a learning tool.
- Can be used as a way to make new compatible products that are cheaper than what it is.
- Cost saving for developing new product because the model is available in advance
- An improvement on material to increase longevity
- Manufacture the part from one piece of material (no welds)
- Customized modification to suit your functionality of any given wear.

1.3 Demerits of reverse engineering

- Super small objects are difficult to reproduce due to current technologies limitation.
- You c never be disassembling an application fully to its original state before compiled.
- If the object is not decent condition i.e., due to wear, warping such things could difficult for getting good scan and requires lots of adjustment.
- There is a problem with patent issue of the design.

1.5 Reverse engineering application

Manufacturing engineering To create a 3D virtual model of an existing physical part for use in 3D CAD, CAM, CAE or other software.

- To make a digital 3D record of own product
- To asses competitors product
- To analyze the working of a product
- To identify potential patent infringement etc
- To analyze the working of a product
- To inspect and compare actual geometry with CAD model
- To measure wear of tools.

Software engineering To extract design & implementation information

- To detect and neutralize viruses and malware
- If the source code itself is not available for the software.

- Security auditing.
- Removal of copy protection.
- To detect and neutralize viruses and malware

Chemical engineering To determine chemical composition

- To substitute or improve recipes to stimulate or improve the product performance

Film-entertainment industry Animated objects are imparted motion using the reverse engineered human skeletons.

- For 3D scanning and rapid surfacing of scale models for animation and film sets.
- For 3D scanning to support online marketing and e presentations
- For bringing real life forms into virtual gaming industry

Medical field Applications in orthopedic, dental & reconstructive surgery

- Imaging, modeling and replication (as a physical model) of a patient's bone structure
- Root cannel of the teeth in dental operation
- Models can be viewed and physically handled before surgery, which gives benefit during evaluation of the procedure and implementation in difficult cases.
- Less risk to the patient had reduced cost through saving in theatre time

Aviation industry The introduction of CFM engine spare parts produced by reverse engineering for the repair and replacement of worn-out components will have significant economic impact on the aviation industry and its customers, who will have more options in their maintenance programs

- The PMA is rooted in the aviation industry. It is both a design approval and a product approval for the reproduction of OEM parts. The criteria of PMA approval are constantly updated along with the advancement of reverse engineering technology.

2 Reverse engineering- Hardware and Software

2.1 Introduction

RE hardware is used for RE data acquisition, which for 3-D modeling, is the collection of geometric data that represent a physical object. There are three main technologies for RE data acquisition: contact, noncontact and destructive. Outputs of the RE data acquisition process are 2-D cross-sectional images and point clouds that define the geometry of an object.

RE software is employed to transform the RE data produced by RE hardware into 3-D geometric models. The final outputs of the RE data processing chain can be one of two types of 3-D data: (i) polygons or (ii) NURBS (non- uniform rational B-splines). Polygon models, which are normally in the STL,

VRML, or DXF format, are commonly used for rapid prototyping, laser milling, 3- D graphics, simulation, and animations. NURBS surfaces or solids are frequently used in computer-aided design, manufacturing, and engineering (CAD-CAM-CAE) applications. Data can be obtained directly using a digitizer that is connected to a computer installed with reverse engineering software. The two most commonly used digitizing devices are probes and scanners. They both measure the part external features to obtain its geometrical and dimensional information.

2.2 Reverse Engineering Hardware

An important part to reverse engineering is data acquisition. Data acquisition systems are constrained by physical considerations to acquire data from a limited region of an objects' surface. Therefore, multiple scans of the surface must be taken to completely measure a part. After reviewing the most important measuring techniques, the related merits and difficulties associated with these methods are discussed. Figure 2.2 classifies the types of application used for acquiring 3D data into contact and non-contact methods

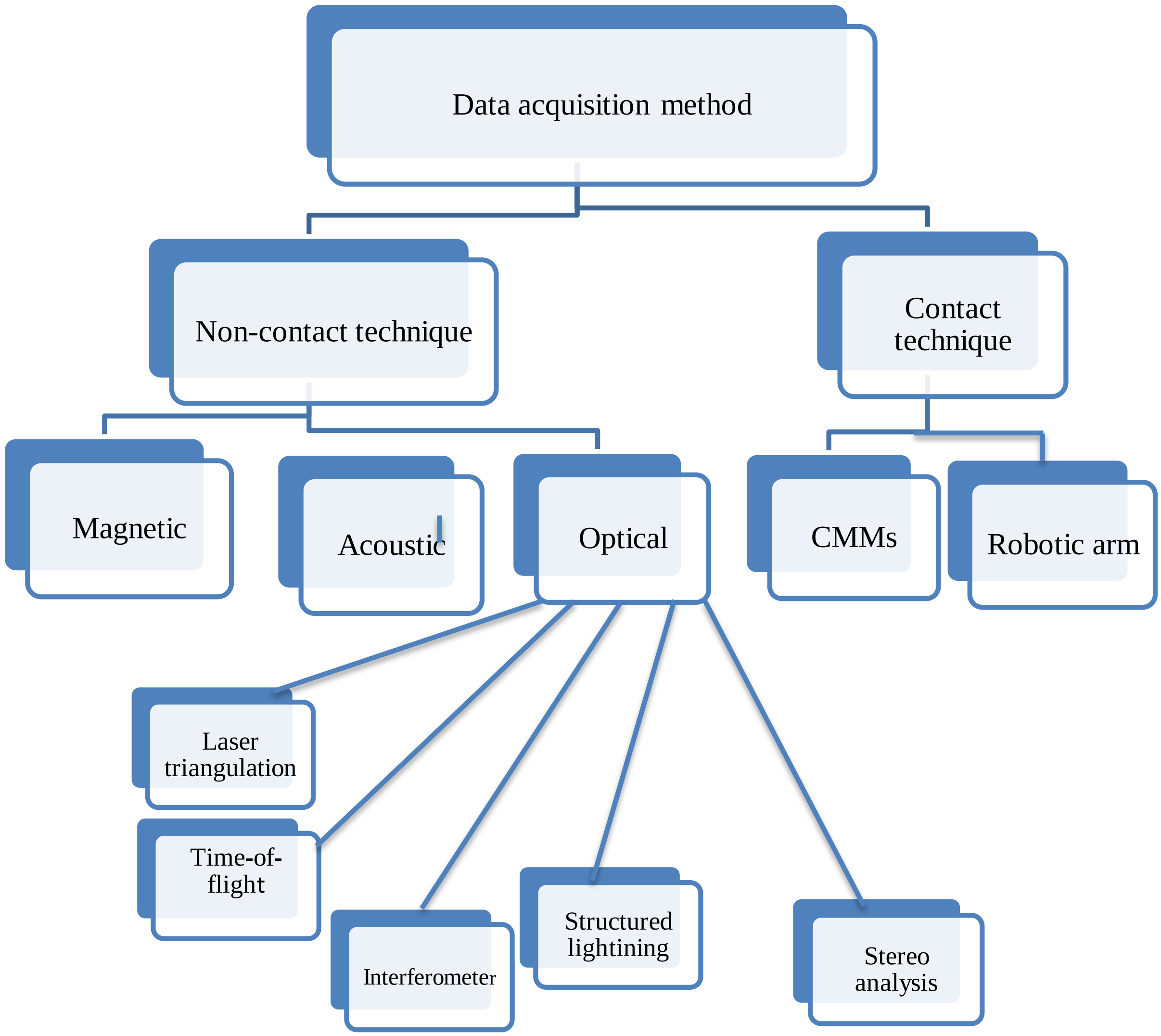


Figure 1.3 Methods in reverse engineering data scanning technique

2.2.1 Contact Methods

Contact methods use sensing devices with mechanical arms, coordinate -measurement machines (CMM), and computer numerical control (CNC) machines, to digitize a surface. There are two types of data collection techniques employed in contact methods.

(i) Point-to-point sensing with touch-trigger probes and

(ii) Analogue sensing with scanning probes.

In the point-to-point sensing technique, a touch-trigger probe is used that is installed on a CMM or on an articulated mechanical arm to gather the coordinate points of a surface. A manually operated, articulated mechanical arm with a touch-trigger probe allows multiple degrees of freedom (DOF) of movement to collect the measurement points (Figure 2.2). A CMM with a touch-trigger probe can be programmed to follow planned paths along a surface. A CMM provides more accurate measurement data compared to the articulated arm. However, the limitation of using CMM is the lack of number of DOF so that a CMM cannot be used to digitize complex surfaces in the same way as an articulated arm.

A 3-axis milling machine is an example of a mechanical or robotic arm. These machines can be fitted with a touch probe, as mentioned before, and used as a tactile measuring system. However, it is not very effective for concave surfaces. There are many different other robotic devices which are used because of their ability to have less noise and have a desirable accuracy, but like the CMM, they are the slowest method for data acquisition.

There are disadvantages when using a CMM or robotic arm to model surfaces of parts. The disadvantages of CMMs having contact to the surface of an object can damage the object. The reason being is if the surface texture is soft, holes can be inflicted on the surface. CMMs also show difficulties in measuring parts with free form surfaces. The part might have indentions that are too small. Flexibility of parts makes it very difficult to contact the surface with a touch probe without creating an indentation that detracts from the accuracy of the measurements.

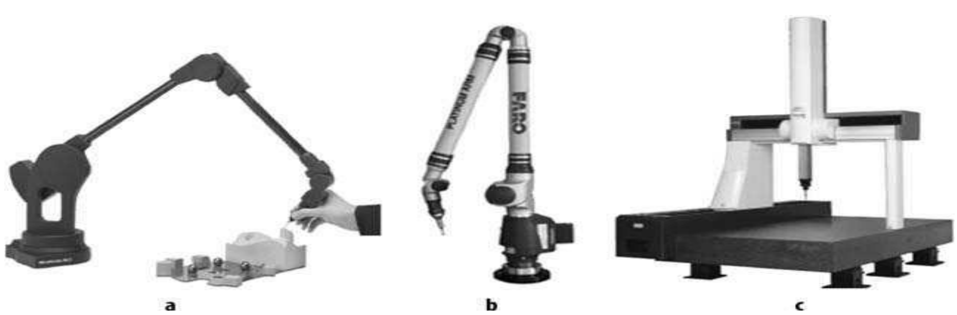


Figure 1.4 (a) Micro Scribe MX Articulated Arm from Immersion Corporation. (b) Faro Arm–Platinum articulated arm from FARO Technologies. (c) Mitutoyo CMM machine–CRA Apex C model

Table 1.1 Gives examples of typical commercial RE hardware that employs contact methods for data acquisition.

Technology	**Company**	**Model**	**Volume (mm)**	**Accuracy, resolution and speed**	**Operation**
Point-to point sensing with a touch-trigger probe, mechanical arms	Faro Technologies	Faro Arm Advantage	1200-3700	Accuracy: ±0.090 to ± 0.431 mm	Manual
		Faro arm platinum	1200-3700	Accuracy: ±0.018 to ± 0.086 mm	
	Immersion corp.	Micro scribe MX	1270	Accuracy; 0.1016mm	Manual
		Micro scribe MLX	1670	Accuracy;0.1270 mm	
Analogue sensing with a scanning probe, CNC machines	Roland DGA Corp.	Picza PIX-30	305×203 × 60	Scan pitch in Y,Y,Z axis: + (X, Y): 0.05–5.0 mm in Steps of 0.05 mm. + Z: 0.025 mm	Programmed
		MDX-15	150×100 × 60		
		MDX-20	200×150 × 60		
Analogue sensing with a scanning probe, CMM and CNC machines	Renishaw Inc.	Renscan 200	Based on the CMM and CNC machine volume	+ Speed: 508–1016 mm/min + Max data rate: 70 points/s	programmed
Point-to-point sensing with a touch- trigger probe, CMM	Mitutoyo	Euro-c-121210	1205*1205*1005	Accuracy;0.001 mm	programmed

2.2.2 Noncontact Methods

In noncontact methods, 2-D cross-sectional images and point clouds that represent the geometry of an object are captured by projecting energy sources (light, sound, or magnetic fields) onto an object; then either the transmitted or the reflected energy is observed. The geometric data for an object are finally calculated by using triangulation, time-of-flight, wave-interference information, and image processing algorithms. There is no contact between the RE hardware and an object during data acquisition.

There are different ways to classify RE hardware that uses noncontact RE methods for data acquisition. These classifications are based on the sensor technologies or data acquisition techniques employed. Figure 3.4 presents a classification of noncontact RE hardware based on data acquisition techniques. The advantages and disadvantages of noncontact methods compared to contact methods are as follows.

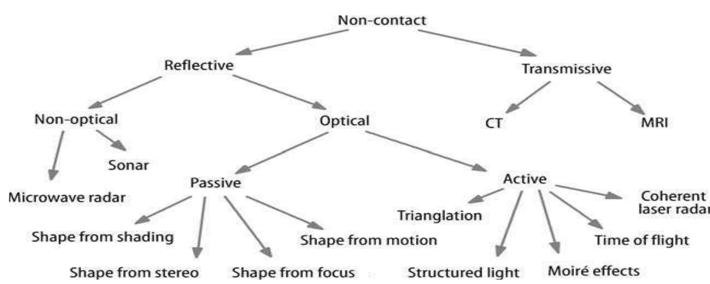


Figure 1.5 Non-contact methods classification

Advantages

(i) No physical contact;

(ii) Fast digitizing of substantial volumes;

(iii) Good accuracy and resolution for common applications;

(iv) Ability to detect colors; and

(v) Ability to scan highly detailed objects, where mechanical touch probes may

Be too large to accomplish the task.

Disadvantages

(i) Possible limitations for colored, transparent, or reflective surfaces and

(ii) Lower accuracy

Optical methods

Optical method of shape capture is probably the broadest and growing in popularity over contact methods. This is because they have relatively fast acquisition rates. There are five important categories of optical methods: laser triangulation, time-of-flight, interferometers, structured lighting and stereo analysis. This section will discuss the various principles of each method.

Magnetic

Magnetic field measurement involves sensing the strength of a magnetic field source. Magnetic touch probes are used which usually sense the location and orientation of a stylus within the field. A trigger allows the user to only record specific point data once the stylus is positioned at a point of interest. Magnetic resonance is used in similar applications to ultra-sound when internal material properties are to be measured. MRI (magnetic resonance) activates atoms in the material to be measured and then measures the response

Laser Triangulation

Most laser scanners use straightforward geometric triangulation to determine
The surface coordinates of an object. Triangulation is a method that employs
Locations and angles between light sources and photosensitive devices (CCD–
Charge-coupled device camera) to calculate coordinates

Two types of triangulation methods

1. Single camera arrangement

In a single camera system, a device transmits a light spot (or line) on the object at a defined angle. A CCD camera detects the position of the reflected point (or line) on the surface.

2. Double camera arrangement

In a double camera system, Two CCD cameras are used. The light projector is not involved in any Measuring functions and may consist of a moving light spot or line, moving Stripe patterns, or a static arbitrary pattern.

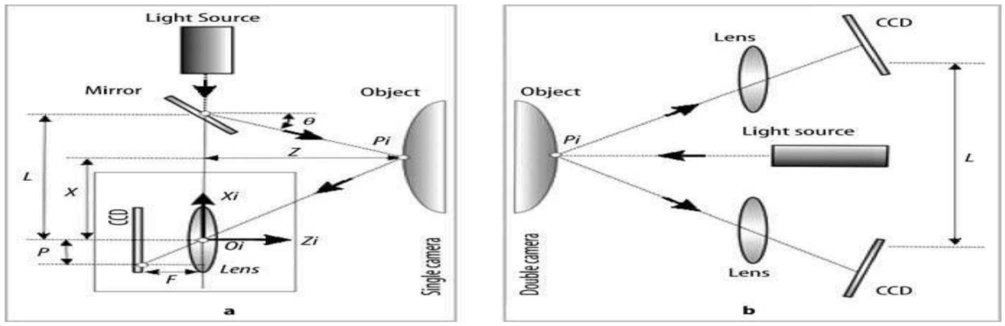


Figure 1.6 Triangulation methods: (**a**) single and (**b**) double camera arrangement

The principle of the triangulation method is shown in Figure 3.5a. A high energy light source is focused and projected at a pre-specified angle (θ) onto the surface of an object. A photosensitive device senses the reflection from the illuminated point on the surface. Because the fixed baseline length (*L*) between the light source and the camera is known from calibration, using geometric triangulation from the known angle (θ), the focal length of the camera (*F*), the image coordinate of the illuminated point (*P*), and fixed baseline length (*L*), the position of the illuminated point (*Pi*) with respect to the camera coordinate system can be calculated as follows

$$z = FL/(P+F\tan\theta)$$

$$X = L - Z \tan\theta$$

The measurement errors in *P* and θ can be determined from the following

Equation:

$$\Delta Z = (Z^2/FL)\times\Delta P\times(Z^2 \sec^2\theta/L)\times\Delta\theta$$

The error in the *Z* measurement is directly proportional to *Z*2 but inversely proportional to the focal length and the baseline length. Therefore, increasing the baseline length can produce higher accuracy in the measurement. For practical reasons, the baseline length cannot be increased at will, and it is limited by the hardware structure of the scanners. Therefore, triangulation scanners are commonly used for scanning small objects over short distances. If the single-point or sheet-of-light pattern is used as the light source, the triangulation scanner is mounted on the travel platform so that it can produce multiple surface scans. Triangulation scanners are supplied both as complete systems and as self-contained scanning heads for mounting on standard touch probe arms or CMMs.

Time of Flight

The principle behind all time-of-flight implementations is to measure the amount of time (t) that a light pulse (i.e., laser electromagnetic radiation) takes to travel to the object and return. Because the speed of light (C) is known, it is possible to determine the distance traveled. The distance (D) of the object from the laser would then be equal to approximately one half of the distance the laser pulse traveled

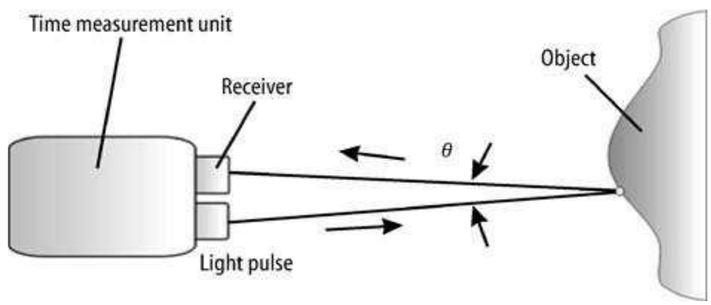


Figure 1.7 Principle of TOF scanners

For all practical purposes, the angle θ is very small and thus has no effect on the accuracy of the TOF distance measurement. The high velocity of light allows TOF scanners to make hundreds, or even thousands of measurements per second.

Advantages

1. They can digitize large distant objects such as buildings and bridges.

2. The accuracy of RE hardware based on TOF is reasonable and approximately between a few millimeters and two or three centimeters for long-range scanners.

3. The shorter the pulse and the faster the detector, the higher the accuracy of the measurement.

Disadvantages

1. TOF scanners are large and do not capture an object’s texture, only its geometry.

2. They are not practical for fast digitization of small and medium-sized objects.
3. They are not practical for fast digitization of small and medium-sized objects.
4. Moreover, it takes time to complete the digitization process because the object (or environment) has to be swept during scanning.

Structured light

In structured-light techniques a light pattern is projected at a known angle onto the surface of interest and an image of the resulting pattern, reflected by the surface, is captured. The image is then analyzed to calculate the coordinates of the data point on the surface. A light pattern can be (i) a single point; (ii) a sheet of light (line); and (iii) a strip, grid, or more complex coded light (Figure 3.6).

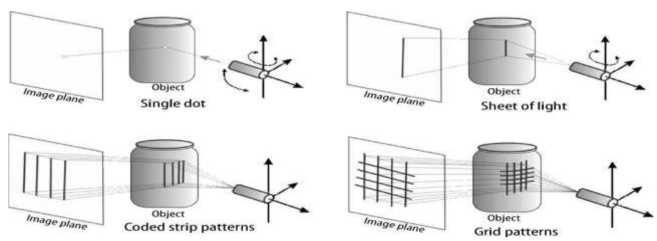


Figure 1.8 Different light patterns used in structured-light techniques

The most commonly used pattern is a sheet of light that is generated by fanning out a light beam. When a sheet of light intersects an object, a line of light is formed along the contour of the object. This line is detected and the X, Y, Z coordinates of hundreds of points along the line are simultaneously calculated by triangulation. The sheet of light sweeps the object as the linear slide carrying the scanning system moves it in the *X* direction while a sequence of images is taken by the camera in discrete steps. An index number k is assigned to each of the images in the order they are taken. Therefore, each k corresponds to the X position of the sheet of light. For each image *k*, a set of image coordinates (*i*, *j*) of the pixels in the illuminated stripe is obtained. The triples (*i*, *j*, *k*) are the range image coordinates; they are transformed to (*x*, *y*, *z*) world coordinates using a calibration matrix.

Advantages

(i) The data acquisition is very fast (up to millions of points per second)

(ii) Color texture information is available

(iii) Structured-light systems do not use a laser.

Acoustic

Where sound is reflected from a surface, *magnetic*, where a magnetic field touches the surface and a hybrid of both contact and non-contact. Acoustic methods have been used for decades for distance measuring. Sonar is used extensively for this purpose. Automatic focus cameras often use acoustic methods to determine range. The method is essentially the same as time-of-flight, where a sound source is reflected off a surface and then distance between the source and surface is determined knowing the speed of sound. Acoustic interference or noise is often a problem as well as determining focused point locations. Dynamic imaging is used extensively in ultra-sound devices where a transducer can sweep cross-sections through an object to capture material data internal to an object.

Stereo Image Analysis

The final optical shape capture method of interest is stereo image analysis. This is similar to structured lighting methods in that frames are analyzed to determine coordinate data. However, the analysis does not rely on projected patterns. Instead, typically, stereo pairs are used to provide enough information to determine height and coordinate position. This method is often referred to as a passive method since no structured lighting is used. Active methods are distinguished from passive methods in that artificial light is used in the acquisition of data. Correlation of image pairs and landmarks within the images are big difficulties with this method and this is why active methods are preferred. Another stereo image analysis approach deals with lighting models, where an image is compared to a 3D model. The model is modified until the shaded images match the real images of the object of interest. Finally, intensity patterns within images can be used to determine coordinate information.

Interferometer

Methods measure the distance in terms of wavelengths using interference patterns. This can be a very accurate method of measurement since visible light has a wavelength of the order of hundreds of nanometers, while most reverse engineering applications distances are in the centimeter to meter range. In principle, other parts of the electromagnetic spectrum could also be used. In practice, a high-energy light source is used to provide both a beam of monochromatic light to probe the object and a reference beam for comparison with the reflected light. Moring et al., describe a range finder based on time-of-flight calculations. The article presents some information on accuracy and performance. Jarvis presents an in-depth article on time-of- flight range finders giving detailed results and analysis.

To conclude this section, all measuring methods must interact with the surface or internal material using some phenomenon, either light, sound, magnetism or physical surface contact. The speed with which the phenomenon operates as well as the speed of the sensor device determines the speed of the data acquisition. The sensor type selected also determines the amount of analysis needed to compute the measured data and the accuracy

2.2.3 General Constraints of Data Acquisition Techniques

There are many practical problems with acquiring useable data, the major ones being:

1. Calibration
2. Accuracy
3. Accessibility
4. Occlusion
5. Fixture
6. Multiple views
7. Noise and incomplete data
8. Statistical distribution
9. Surface finish

2.3 REVERSE ENGINEERING SOFTWARE

2.3.1 Introduction

Software reverse engineering is defined as "the process of analyzing a subject system to create representations of the system at a higher level of abstraction". Abstraction is a concept or idea without affiliation with any specific instance. In software development, the higher abstraction levels typically deal with concept and requirement, while the lower levels accentuate design and implementation. Generally speaking, reverse engineering performs transformations from a lower abstraction level to a higher one, restructuring transformations within the same abstraction level; while forward engineering performs transformations from a higher abstraction level to a lower one.

2.3.2 Reverse engineering software classifications

There is no single RE software that can completely satisfy the requirements of RE data processing and geometric modeling. The selection of RE software depends on the specific requirements of RE projects

s.no	Application	Main function	Software
1.	Hardware control	Control RE hardware for data Acquisition. Normally, basic data Processing operations and data Conversion are also provided.	Mitutoyo Cosmos, Hymarc, Metris Scan, Cyber ware CyDir and GSI Crystal Studio.
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.	ICEM surf, Image ware and other common CAD Packages such as UG, Pro Engineer and Solid works.

3.	Polygon manipulation	3-D polygon data editing, Modification and optimization.	Magic's RP, DeskArtes, Catia Shape Sculptor and Viscam 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, Rapid form, Geomagics, Polyworks (Modeler) and Paraform.
5.	2-D Scan Image Processing and 3-D modeling	Used for processing 2-D scan images (CT/MRI) and 3-D reconstruction.	Mimics, Rapidform, Bio Build, Velocity2, Amira, Scan IP, Analyze and 3-D Doctors.
6.	3-D Inspection	Used for 3-D inspection, error map creation and analysis, inspection report and Documentation.	COMET inspect, Metris Focus Inspection, Power INSPECT, Polyworks Inspector and Geomagic Qualify.
7.	NURBS surface and solid modeling	Provide NURBS modeling and editing tools based on basic CAD Entities and primitives.	Pro Engineers, UG, Solid works, Catia and Rhino.

Table 1.2 Reverse engineering software classification based on application

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 Modeling, 3-D inspection, and NURBS surface and solid modeling. Table 3.1 presents these RE software groups with representative commercial packages.

2.3.3 Reverse Engineering Phases

For an overall view of RE software operation, the different RE data processing phases will first be described. The required RE operations are then considered. The complete RE data processing chain, from scan data to the final NURBS model, can be divided into four main phases: points and images, polygon, curves, and NURBS surfaces. Figure 3.1 presents the four phases of the RE data processing chain with the fundamental RE operations. These RE operations are necessary and are available with the most commonly used commercial RE software such as GSI Studio, Geomagics, Copy CAD, Rapidform, Polyworks, Paraform, ICEM surf, and Magic's RP.

Points and image phase In the points and images phase, scan data are registered, prepared, and optimized for constructing 3-D polygon models. Outputs from the RE data acquisition process are 2-D cross-sectional images or point clouds. RE systems that use transitive techniques such as CT and MRI provide a large series of 2-D cross-sectional images of an object.

Polygon phase In this phase, polygon models are constructed. They are then manipulated and controlled to meet the requirements of the applications. The resulting 3-D polygon models are directly employed for rapid prototyping or are used as reference data for creating CAD entities (points, curves, and primitives) and constructing NURBS surface

Curve phase In many RE projects, especially RE of mechanical parts, CAD entities are mainly used as the reference data for geometric modelling in CAD packages. The CAD entities are constructed directly from point clouds or indirectly from polygon models by manual editing, fitting, and sectioning operations.

NURBs surface NURBS surfaces are sometimes the ultimate RE output for CAD-CAM-CAE applications. NURBS surfaces can be constructed based on the CAD entities extracted from the curve phase or by using polygon meshes for surface fitting

Point and image phase

Registration Manual and automatic alignment.
Data optimization Noise and point redundancy reduction, sampling points and identifying primitives.
Basic operation Rotate and move, datum control and separating and merging.
Image processing Region growing and thresholding

Polygon phase

Polygon optimization Noise reduction and cleaning, abnormal phases cleaning
Polygon edit and control Filling holes, defeaturing, edge detection and sharpening control, primitives fitting, polygon editing and remeshing
Basic operation Rotate and move, datum control, Boolean, offset, shell, thicken, cut and merge

Curve phase

Primitive fitting: circle, cylinder and plane.
Curves construction: cross-section and curve fitting from points.
Curve modification and editing: curve re-parameterization, curve degree conversion, curve smooth and clean, control point edit, transition and extension, point generation and curve re-direction

NURBS surface phase

Surface from curve Loft, uv-network and extrude.
Patch creation & control Curvature detects, patch editing and patch temple re-use.
Nurbs surface creation & control Grids, Nurbs patches merging, Nurbs surface smoothing and editing
Evaluation Point to CAD, polygon to CAD, CAD to CAD

Figure 1.9 Four phases of the RE data processing chain with fundamental RE operations

3 Additive Prototyping

3.1 Introduction

The term additive prototyping (AP) refers to a class of technologies that are used to produce physical objects layer-by-layer directly from computer-aided design (CAD) data. It reflects one of the most distinctive features of this technology, much faster production of a tangible model part compared to traditional machining and other manufacturing processes. Prototyping revolutionizes the model part creation in machine design and reverse engineering, and provides designers with a tool to quickly convert a conceptual design idea into a physical model part. It helps engineers to visualize the design drawing and computer modeling. This process usually starts with the input of data from a CAD model that is an intermittent product of reverse engineering. A slicing algorithm first slices the CAD model into a number of thin layers and draws the detailed geometric information of each layer, and then transfers it to the prototyping machine. The final model part precision is directly related to the thickness of the slicing layers. For consistency, the STL format has been adopted as the industrial standard slicing algorithm. However, depending on the software, a CAD model can be built with various formats, such as DXF, 3DM, or IGES. Figure 1.10 a shows a simulated solid model of a sample part on the computer screen. This information is transferred to a 3D printer for prototyping, as shown in Figure 1.10 (a) figure 1.10 (b) Figure 1.10 (c) shows the final prototype part produced by the 3D printer.

Besides visual aids for communicating ideas with coworkers or customers, these prototypes can be used to test various aspects of their design, such as wind tunnel tests and dimensional checks. In addition to the production of prototypes, additive prototyping techniques can also be used to produce molds or mold inserts (rapid tooling) and even fully functional end-use parts (additive manufacturing).Because these are Nano prototyping application, rapid prototyping is often referred to as solid free-form fabrication or layered manufacturing.

Figure 1.10 Data transferring on the monitor screen

For small series and complex parts, these techniques are often the best manufacturing processes available. They are not a solution to every part fabrication problem. After all, CNC technology and injection molding are economical, widely understood, available, and offer wide material selection.

Depending on the dimensions of the object, production times can be as long as a few days, especially with complex parts or when long cooling times are required. This may seem slow, but it is still much faster than the time required by traditional production techniques, such as machining. This relatively fast production allows analyzing parts in a very early stage of designing, which decreases the resulting design cost.

3.2 General definition

The additive prototyping process is a nonconventional fabrication technology that is supported by modern information technologies for data conversion, CAD model building and slicing, and model part fabrication. This process usually starts with the input of data from a CAD model that is an intermittent product of reverse engineering. A slicing algorithm first slices the CAD model into a number of thin layers and draws the detailed geometric information of each layer, and then transfers it to the prototyping machine to build up semi-two-dimensional sections layer by layer with skinny thickness. The final model part precision is directly related to the thickness of the slicing layers. For consistency, the STL format has been adopted as the industrial standard slicing algorithm

However, depending on the software, a CAD model can be built with various formats, such as DXF, 3DM, or IGES. The DXF, short for drawing exchange or drawing interchange, format is a CAD data file format developed by Autodesk in 1982. For many years the data exchange with the DXF file has been challenging due to lack of specifications. The 3DM is a computer graphics software format developed for free-form NURBS modeling and to accurately transfer 3D geometry between applications. A direct application of the original point cloud data to slicing algorithm and layer modeling in additive prototyping technologies, if successfully developed, will have the potential to significantly improve the model part surface finishing, precision, and tolerance.

3.3 The Basic Process

Additive prototyping techniques share the following process steps (see Figure 1.11):

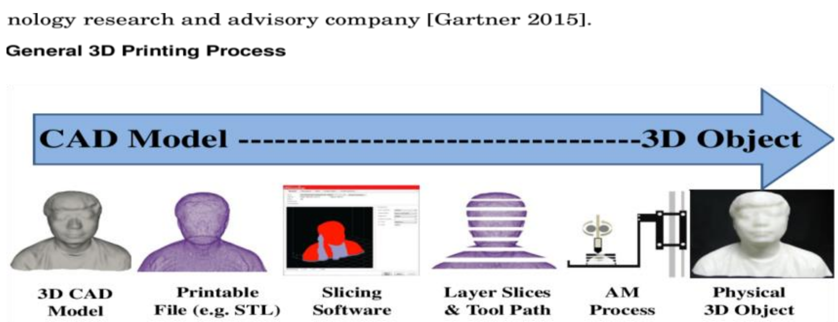


Figure 1.11 Basic process of additive prototyping

1. Creating a CAD model either by designing a new or scanning an existing object.

2. Converting the CAD data to STL format. Because the various CAD packages apply a number of different algorithms to represent solid objects, the STL format (Standard Triangulation Language) has been adopted as the standard of the rapid prototyping industry to establish consistency. This STL file is a concrete visualization of the product geometry, built up from triangles. Using triangles to describe a surface, curved surfaces can only be approached. Increasing the number of triangles (i.e., increasing the resolution) yields a better approach. However, it also enlarges the STL file. So, one has to find the optimum balance between file size and part accuracy.

3. Slicing the STL file into thin cross-sectional layers. After the STL file has been sized and oriented, it is sliced in layers with a predefined thickness.

4. Generation of a support structure. This additional step is not required for all techniques. Because the model is built up in layers, there may be areas that could float away or have

overhanging features, which could distort the resulting model. A base and support structures have to be added, which can be easily removed after the building step.

5. Producing the model layer-by-layer. The generated slices are reconstructed in the machine by building one layer at a time. This can be fully automatic.

6. Post processing, this step enhances cleaning and finishing the model and (if a base or support structure was built) removing the support structure. Some materials need to be post cured or infiltrated to achieve optimal properties

3.4 Current Techniques and Materials

A wide range of techniques and materials can be used for rapid prototyping. There are more than ten commercial rapid prototyping processes and more than five concept modeling processes; all have unique properties. Due to worldwide research, this range is growing quickly. Commercial techniques are available to produce objects from numerous plastics, ceramics, metals, and wood-like paper. Among these techniques are

• Stereo lithography

• Selective laser sintering

• Fused deposition modeling

• Three-dimensional printing

• Laminated object manufacturing

• Multijet modeling

• Laser-engineered net shaping

3.4.1 Stereo lithography

Stereo lithography (SLA) is the first commercialized additive rapid prototyping process, and is still the most widely used additive prototyping technology today. In U.S. Patent 4,575,330, “Apparatus for Production of Three-Dimensional Objects by Stereo lithography,” issued on March 11, 1986, Hull, who invented the technology of stereo lithography, defined it as a method and apparatus for making solid objects by successively "printing" thin layers of the ultraviolet curable material one on top of the other.

A platform is placed in a bath of photosensitive UV-curable resin at a level that leaves a small layer of resin between the top of the platform and the surface of the bath. A laser (often He-Cd or argon ion to produce UV radiation of about 320–370 nm wavelength) then strikes the desired areas, thereby curing the resin selectively. As the layer is completed, the platform descends allowing liquid resin to flow over the previously cured area. A wiper blade clears the excess fluid from the top of the surface. This sweep is essential to achieve consistent layer thickness and prevent air entrapment. As the new layer is cured, it sticks to the preceding layer. This process continues until the object is completed. On completion, the object raises above the fluid, so that resin can drain out. The object is carefully removed and washed in a solvent to remove uncured resin. The cleaned object has to be placed in a UV oven to ensure that all resin is cured. During the process, features that lean over have to be supported. This support structure can easily be generated by software and consists of a series of slender sacrificial columns or lattices.

Characteristics

• Long-term curing can lead to over curing which leads to war page.

• Parts can be quite brittle.

• Support structures are required.

• Uncured material can be toxic

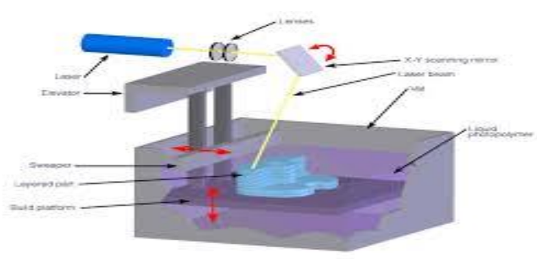


Figure 1.12 Stereo lithographgy

3.4.2 Selective laser sintering

Selective laser sintering (SLS) is another additive prototyping process that builds parts by sintering powdered materials by a laser, layer by layer, from the bottom up. This technology was developed by Carl Deckard at the University of Texas at Austin, and subsequently patented by him in 1989.Sintering is a fusion process at a temperature above one-half the material melting temperature, but below the melting temperature. Sintering welds two or more particles together and consolidates them into a solid part, usually under pressure

A layer of powder (particle size approximately 50 μm) is spread over a platform and heated to a temperature just below the melting temperature. A carbon dioxide laser needs to raise the temperature only slightly and selectively to melt the powder particles. As the layer is finished, the platform moves down by the thickness of one layer (approximately 0.10–0.15 mm), and new powder is spread. When the laser exposes the new layer, it melts and bonds to the previous layer. The process repeats until the part is complete.

Characteristics

• Key advantage of making functional parts in essentially final materials.

• Good mechanical properties, though depends on building orientation.

• Powdery surface

• Many variables to control

• No support required

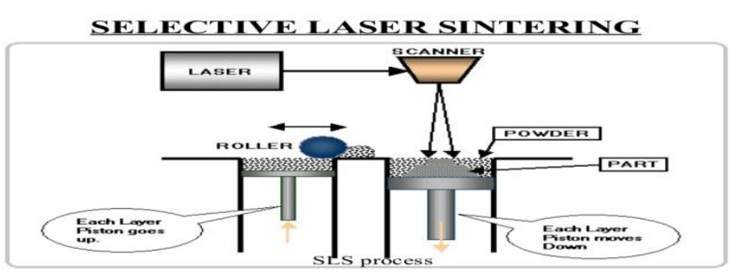


Figure 1.13 Selective laser sintered

3.4.3 Fused Deposition Modeling

Fused deposition modeling (FDM), developed by Stratasys, is also an additive process. It is a very popular rapid prototyping technology and is widely used, only second to SLA

It builds parts from the bottom up through a computer-controlled print head. In contrast to SLA, whereby a liquid resin pool is used, and SLS, whereby the compacted resin powders are used, the feedstock for FDM is a filament of extruded resin that remelts and deposits on top of the previously formed layers. The FDM process utilizes a variety of polymeric materials, including acrylonitrile butadiene styrene (ABS), polycarbonate, and polyphenylsulfone. The ceramic and metallic materials are also potential candidate materials that can be used in the FDM process in the future. The FDM parts are relatively strong with good bonding between the layers, and can be used for functional tests in reverse engineering when appropriate. However, the FDM parts are often porous, with a rough surface finish, and of relatively poor tolerance control

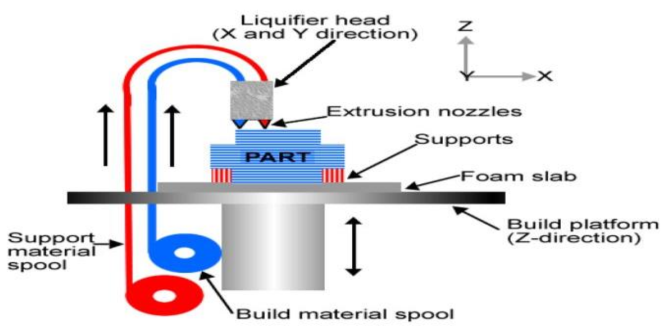


Figure 1.14 Fused deposition system

Characteristics

- Office-friendly and quiet.
- FDM is fairly fast for small parts.
- Good mechanical properties, so suitable for producing functional parts.
- Wide range of materials.

3.4.4 Three-dimensional Printing

In this process, a layer of powder is spread over a platform. The particles are bonded together selectively by a liquid adhesive (binder solution). This liquid is deposited in a two-dimensional pattern by a multichannel jetting head. As the current layer is completed, the platform moves down by the thickness of a layer, so that a new layer can be spread. This process is repeated until the entire object is formed within the powder bed. On completion, the object is elevated and the extra powder is brushed away, leaving a fragile “green” object. It is necessary to infiltrate the part with another material to improve mechanical characteristics.

No support structures are required because the surrounding powder particles support overhanging features. By adding color to the binder solution, objects can be produced in every desired color. Starch, plaster, medicines (for producing controlled-dosage pharmaceuticals), ceramics, and metals are commonly used materials (powders) for 3-DP.

Characteristics

• Limitations on resolution and surface finish.

• Fragile objects need to be infiltrated.

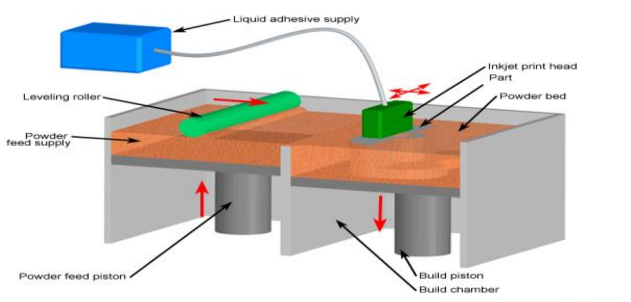


Figure 1.15 Three dimensional printing method

3.4.5: Laminated Object Manufacturing

In laminated object manufacturing (LOM), a sheet of paper (unwound from a feed roll) with a polyethylene coating on the reverse side is placed on a platform. This coating is melted by a heated roller, making the paper adhere to the platform. Then, a carbon dioxide laser cuts out the cross -section of the object and a border. The laser also creates hatch marks, or cubes that surround the pattern within the border. These cubes behave as a support structure for the model. When the laser has finished the layer, a new paper sheet is applied.

Upon completion, the model is captured within a block of paper. When all of the surrounding cubes have been removed, the unfinished part is sanded down. The humidity and temperature dependency of the paper material can be reduced by coating the model. The finish and accuracy are not as good as with some other methods; however, objects have the look and feel of wood and can be worked and finished like wood.

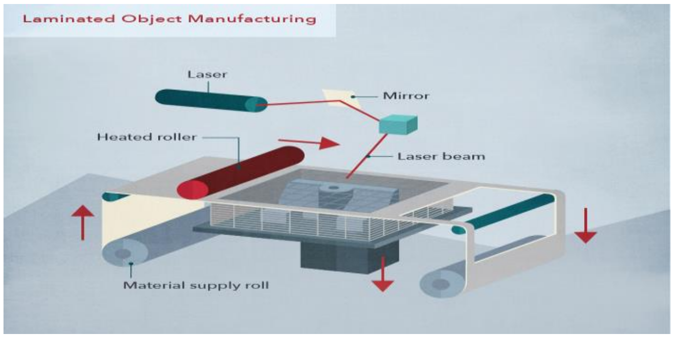


Figure 1.16 Laminated object manufacturing

3.4.6: Multijet Modeling

Multijet modeling (MJM) uses multiple print heads to deposit droplets of material in successive, thin layers. A 96-element print head deposits droplets of wax. Because of its relatively fast production, this technique is marketed to the engineering or design office for quick form studies (concept modeling). However, wax models can also be used as master patterns for investment casting.

A print head jets two separate materials, an acrylic UV-curable photopolymer-based model material and a wax-like material to produce support structures for the model. Due to the relative good quality of the models, production speed, and surface finish, applications range from preliminary prototypes to mock-ups for concept proposal or marketing models.

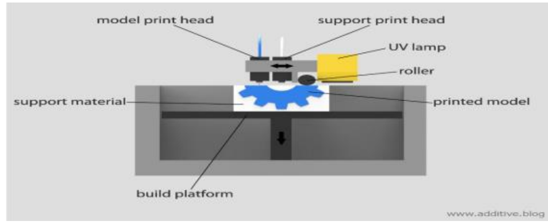


Figure 1.17 Multijet modeling

3.4.7: Laser-engineered Net Shaping

In laser-engineered net shaping (LENS), a laser beam focuses onto a metal substrate to melt the upper surface. A deposition head then applies metal (powder or fine wire) into the molten puddle to increase the material volume. By moving the platform in raster fashion, each layer of the object is fabricated. An inert gas is used to shield the melt puddle from atmospheric oxygen for better control of properties and to promote layer-to-layer adhesion by providing better surface wetting.

Fully dense metal parts (made of stainless steel, aluminum, copper, Inconel, titanium, etc.) can be produced by LENS. It is even possible to change the material composition dynamically, which lead to objects with properties that might mutually exclusive using traditional fabrication methods. Although produced parts are near net shape, they generally require post processing. Applications of LENS are injection molding tools and aerospace parts.

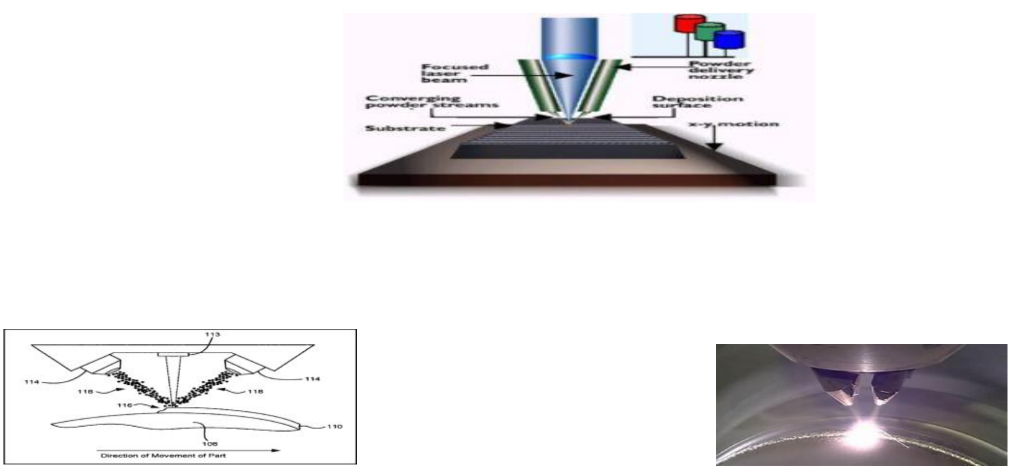


Figure 1.18 Laser engineered net shaping

3.5 Merits of additive prototyping

- **Freedom of design** The production of complex parts is reduced to the accumulation of layers.
- **Well automated** No supervision is needed during the build process.
- **Relative easy to employ** Only little preparation and post processing are required.
- Avoiding the high cost of prototype tooling, allowing (more) design iterations.
- Physical models are easy to check for errors.
- It can create parts with complicated internal features that are difficult to manufacture.

3.6 Demerits of additive prototyping

- Accuracy generally >0.1 mm.
- **Material properties** Products can be very fragile, and some need post processing before they can be handled (as with 3-DP).
- **Stair casing effect** Because an inclined surface is constructed using several layers, stair casing will occur.
- Most additive prototyping technologies do not provide any information On part machinability and manufacturability of the design.
- The additive prototyping technologies are also subject to some other restrictions, such as part size, applicable material, and limited production.
- Metal prototypes are noticeably difficult to make with the additive prototyping process.

3.7 Application of additive prototyping

Aerospace

NASA engineers drew on ingenuity and advanced technology. About 70 of the parts that make up the rover were built digitally, directly from computer designs, in the heated chamber of a production-grade Stratasys 3D Printer. The process, called Fused Deposition Modeling (FDM) Technology or additive manufacturing, creates complex shapes durable enough for Martian terrain [7].For its 3D-printed parts, NASA uses ABS, PCABS and polycarbonate materials. FDM, patented by Stratasys, is the only 3D-printing method that supports production-grade thermoplastics, which are lightweight but durable enough for rugged end-use parts.

Health

While much effort is put forth by individuals, societies, and businesses to improve our physical health, an ideal health is very subjective and could depend on location and vary over time. However, it can be said that the absence of sickness, specially, chronic illnesses is a requisite for good health. Illnesses, accidents, and aging deteriorate the body's or a specific organ's condition. Organ transplants have been successfully conducted for the past century; however, there has always been a shortage of donors or an inability to find a match between the donor and recipient in time. 3D printing is an advanced recent technology in this field which can be a revolutionary alternative with a variety of applications in the transplant and healthcare industry in general. 3D printing research is investigated in various fields within the healthcare industry; some of which are discussed in this section.

Architecture industry

Poly-Jet 3D printing technology produces astonishingly smooth, detailed architectural models in an array of materials, including rigid photopolymers ready for painting. For models that must bear loads or take abuse, FDM Technology builds strong parts in production-grade thermoplastics.

Dental implants

Dental industry has been using artificial material for dentures, orthodontics, implants, crown, and bridges for many years. As these parts are custom made for each person, the process is both time consuming and expensive. Direct and indirect 3D printing, namely printing the actual part or a mold, has been shown to be a cheaper and faster alternative to conventional technique.

Skull and jaw implant

Researchers have shown that 3D printed parts can be used as bone replacement for people whom lost part of their skull or jaw in an accident.

Automobile industry

One of Ducati's key challenges is to reduce time-to-market for new products by reducing the design cycle. To help meet this challenge, the entire design process is validated using FDM prototyping systems from Fortus. FDM (fused deposition modeling) enables Ducati to build both concept models and functional prototypes from ABS, polycarbonate and poly-phenylsulfone.

Jigs and Fixtures

Inkjet-based technology and FDM Technology, both available from Stratasys, provide fast and accurate methods to produce and manufacture tools. 3D printing jigs and fixtures with inkjet or FDM can help reduce the backlog for an in-house machine shop and be used as a bridge-to-tooling solution.

Education

The education system plays an important role in aiding people achieve their full potential. 3D printing can revolutionize the learning experience by helping students interact with the subject matter. Affordable 3D printers in schools may be used for a variety of applications which can aid students in finding their field of interest easier and faster. Currently there are different types of educational projects in order to attract students to the various fields by giving them the opportunity to create and fabricate their own designs using 3D printing technology.

Chapter-II

Literature review

Every research is undertaken by doing a thorough review of the development and research work undertaken in the specific area/domain of the given research work. In a to do justice to the given proposed work to be get a better insight, the following literature is carried out for the analysis of the existing system working and also critically evaluated, to find if there are any shortcomings.

A substantial research is carried out in these fields by researchers. This part of study enlightens briefly on some of work done by those researchers. The work from various books, papers, articles, journals has been referred for this purpose it is humble approach to thank those researchers whose work done will be referred in this research. Some of them are mentioned in the article.

Reverse engineering

A. Kumar et.al. (2014) [1] provided a technique for measurement and inspection of machine element using reverse engineering tool. Their study uses a spur gear which wears out during operation due to friction. The methodology includes scanning of worn out spur gear to obtain the point data, generation of surfaces and creating a 3D model, and final step is comparing the two model i.e. model obtained after scanning of worn out part to that of obtained from actual gear tooth profile so that worn area can be recognized and further action of maintenance can be applied.

H. Wu et.al. (2013) [2] have reviewed several algorithms based on geometric reconstruction and repairing methodologies for gas turbine component which is a critical component because of its complexity in shape and high cost of repair. The paper includes different types of algorithms for the repairing solutions of damaged blades. The process of repair and overhaul is a five stage process: pre repair inspection, identification, surface reconstruction of defected surface, welding, milling and grinding. They also concluded that available reconstructing approaches are not efficient so future work is required in this field.

Bhupender Singh et. al. (2011) [3] presented the solid modeling and finite element analysis of crane boom using PRO/E WILDFIRE 2.0 and ALTAIR HYPER MESH with optistruct 8.0 solver Software to get the variation of stress and displacement in the various parts of the crane boom and possible actions were taken to avoid the high stress level and displacement. The solid model was created using pro/E Wildfire 2.0 using given dimensions. Then the solid model was imported to ALTAIR HYPER MESH and analysis of the model was carried out in OPTISTRUCT SOLVER 8.0 under given constraints. The stress values calculated for three load points were found to be under the limits of ultimate tensile strength and yield strength of boom material. So it can be said that under the given conditions of boom material and load carrying capacity, crane boom was safe to lift the load up to 12 Tonne

E. Bagci (2009) [4] defined the reverse engineering process as the five stage process which includes digitization, data capturing, processing phase, surface approximation (for solid modeling), technical documentation and, NC part programming and CNC milling machine (for the part manufacturing) using three samples which were broken and worn in some regions. Components used for study are damaged cam-worn due to friction, turbine blade and a defected Ataturk's bust. These components were recreated using RE and modifications have been made to them in order to recover their final geometry. After recovery CAD models were used for part manufacturing using a CNC milling machine.

M. Manzoor Hussain et. al. (2008) [5] presented the development of computer technology resulted in the integration of design and manufacturing systems and automated inspection/gauging systems in manufacturing engineering applications. Geometrical information of a product was obtained directly from a physical shape by a digitizing device, from this complete 5-axis tool path was obtained. Duplicating the part was done with the help of CMM and CAD/CAM software like Mastercam, ProEngineer etc. CMM was used to digitize the mechanical object. Taking coordinates (scan data) of the various points on the surface of the object and converting it into IGES file and using the same in the CAD/CAM software with required interfacing created a surface or solid model of the object. Finally this solid model was used to generate CNC part program to manufacture the part on CNC Machining center.

Lin et al. (2005) [6] had presented the measure method to get the better data points and the appropriate method to deal with points cloud data. Reverse engineering software was then used to create the free-form surfaces from the point cloud data.

Rapid prototyping

3D printing was known as "rapid prototyping". Chuck Hull, of 3D Systems Corporation, created the first working 3D printer in 1984 [7]. Later in the 80's, Selective Laser Sintering (SLS) technology was developed by Dr. Deckard at the University of Texas at Austin during a project sponsored by Defense Advanced Research Projects Agency (DARPA). In the 1990s, the technology was further improved with the development of a method that used ultraviolet light to solidify photopolymer, a viscous liquid material.

D.A. Roberson et al. [8] evaluated the capability of five desktop additive manufacturing (AM) machines based on the ability to produce a standard component. This work also developed a model/method for evaluating and ranking AM technologies based on select criteria that can facilitate purchasing decisions. A standard part was designed and printed on each machine, and evaluated based on dimensional accuracy and surface finish. Additionally, the machines were compared based on build time for single and multiple parts as well as material consumption and unit cost. The ranking system presented in this paper has demonstrated the ability to discriminate between different AM processes and rank these systems based on quantitative measures.

Lee and Kim [9] analyzed the trend of 3D printing-related patents for the last 10 years to investigate patent application trends by country, by year, by assignee and by technology. Furthermore, the paper analyzed the patent trend on 3D printers and materials used to secure original technologies and a portfolio of application technologies in medium and long terms.

Berman [10] in his paper examined the characteristics and applications of 3D printing for mass customization. He argued that there are a number of promising applications exist in the production of replacement parts, dental crowns, and artificial limbs, as well as in bridge manufacturing. 3D printing market allow firms to profitably serve small market segments, and enable companies to operate with little or no inventory and significantly reduce the need for factory workers.

Huang [11]et al. reviewed the societal impact of additive manufacturing in (1) customized healthcare products to improve population health and quality of life, (2) reduced environmental impact for manufacturing sustainability, and (3) simplified supply chain to increase efficiency and responsiveness in demand fulfillment. Their review also identified the need for further research in the areas of life-cycle energy consumption evaluation and potential occupation hazard assessment for additive manufacturing.

Chapter-III

Methodology and material study

1 Study of model

The present study is based on the reconstruction of the foot valve mesh that is used for the suction of the underground water and to control the reverse flow of the water due to gravity. The component which we see in the Figure 3.1 is corroded due to which capturing of its original dimension is difficult task for us, more over the component was also damaged.

Figure 3.1 Assembly of foot valve mesh

2 Methodology

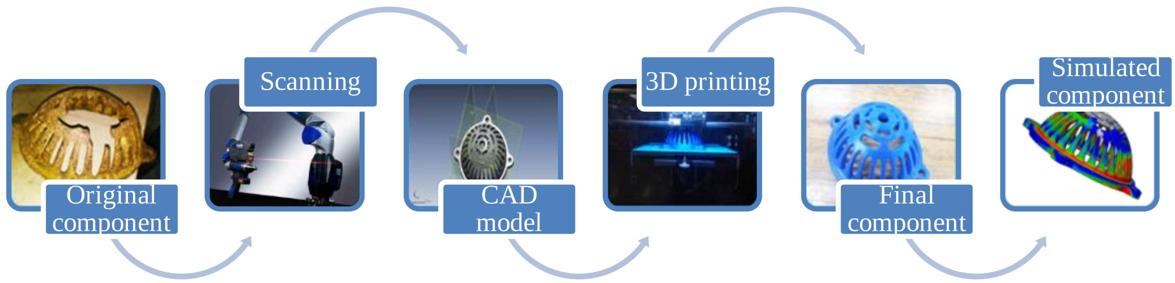


Figure 3.2 Process performed

In first stage of operation original component selected is scanned by using laser scanning to get point cloud which is triangulated and saved in .STL format. The file was imported in the reverse engineering software where the remodelling of the component and conversion into CAD format was done sent to the additive prototyping (3D printing) Machine. Here the plastic 3D printed part is fabricated then finally compared with the

Original one.

2.1 Acquisition of raw point clouds data

Digitization of the model was made with an active non-contact scanning process using a portable laser scanner (Shining 3D EinScan-Pro) is shown in Figure below. The acquisition system of points was controlled automatically by software of equipment (EINSCAN-S). 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.

2.1.1 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.

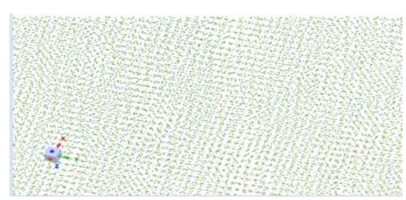
2.1.2 Noise reduction

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.

2.1.3 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 center of each grid is retained as shown in the Figure 6.3.

(a)



(b)

Figure 3.3 Point cloud data a) with sampling. b) Without sampling

2.1.4 Wrapping

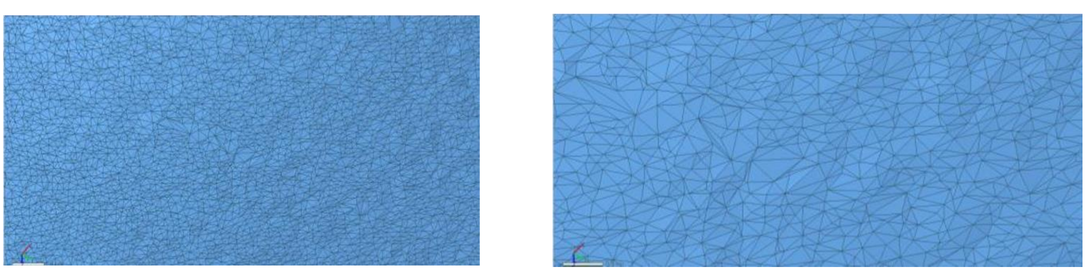
Wrapping is a process of converting a point object to a polygon object. It is advantageous to wrap a point object because there are many refinements that can be performed on a polygon object that cannot be performed on a point object. The method works by maintaining a list of points from which the mesh can be grown and extending it until all possible points are connected. 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 neighborhood of a point along its normal connecting the unconnected points.

2.1.5 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.

2.1.6 Simplifying Model (Reducing Triangles)

'Simplify' allows reducing the number of triangles as shown in figure 3.4 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 3.4 Meshing a) without simplifying b) with simplifying

2.17 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.

- **Curvature Fill** Specifies that the new mesh that fills the selected holes must match the curvature of the surrounding mesh.
- **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.
- **Flat Fill** Specifies that the new mesh that fills the selected holes is generally flat.

2.2 Component description

A damaged foot valve mesh is selected for the project of reverse engineering which is in the figure 3.5. The component has been corroded and having few broken parts. Recovering of the dimensions is difficult. This part is used for filtering water during suction which is assembled with foot valve for lifting of water with the help of motor from ground level. The objective of selecting this component is to learn how to design and reconstruct of such damaged and broken parts with the help of reverse engineering software.

Figure 3.5 original component

2.3 Data scanning

A Point Cloud data which is in the .ase format meshed and it is saved in .stl format as shown in the figure 3.6. This process generates mesh type of faceted triangular surface. This surface is not a CAD surface and still needs to be converted which is in the form of a solid model.

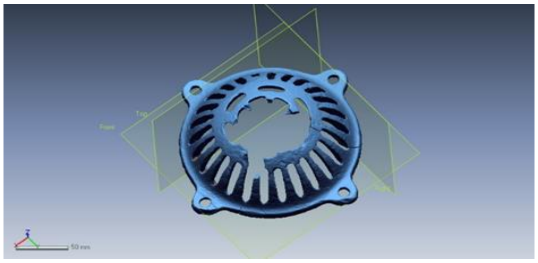


Figure 3.6 Mesh STL format

Steps in conversion

- Triangulate Tool: It is used for converting a point cloud into a mesh object.
- Mesh Construction: Used for meshing and merging of multiple meshes.
- Healing Wizard and Fill Holes tool: As the Name suggests it is used for Hole filling and healing defects

2.4 Modeling

The mesh .stl file is then imported in the reverse engineering software there using the modeling tools such as extrude, surface revolve, circular pattern, bolean the component was remodeled. The restored model as shown in the figure 3.7 is converted into the CAD file format which is extreme file is sent to the 3d printing machine, now the part is ready to undergo additive prototyping process.

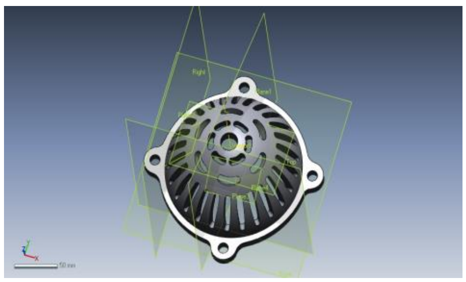


Figure 3.7 Remodeled CAD format component

2.5 Additive prototyping

The additive prototyping machine named Trovole FDM dual extruder 3D printer is used for printing the component. The CAD format file which is sent to the 3D printing machine is stored. Here the PLA (polylactic acid) filament that is in the form of wire of diameter 1.75mm is wound around the spool and installed in the machine. PLA filament is widely thought of as an aesthetic material best used for prototyping. Hence the PLA filament melts at temperature limit of 180 ° - 230 ° and generates the prototype by adding layer by layer with a time lapse 5h 25m as shown in the figure 3.8.

2.5 Material properties of PLA

- **Strength:** High/ **flexibility** low/ **durability** medium.
- **Difficulty to use** Low
- **Print temperature** 180 ° - 230 °
- **Print bed temperature** 20° - 60° (but not needed)
- **Shrinkage/ wrapping** Minimal
- **Soluble** No

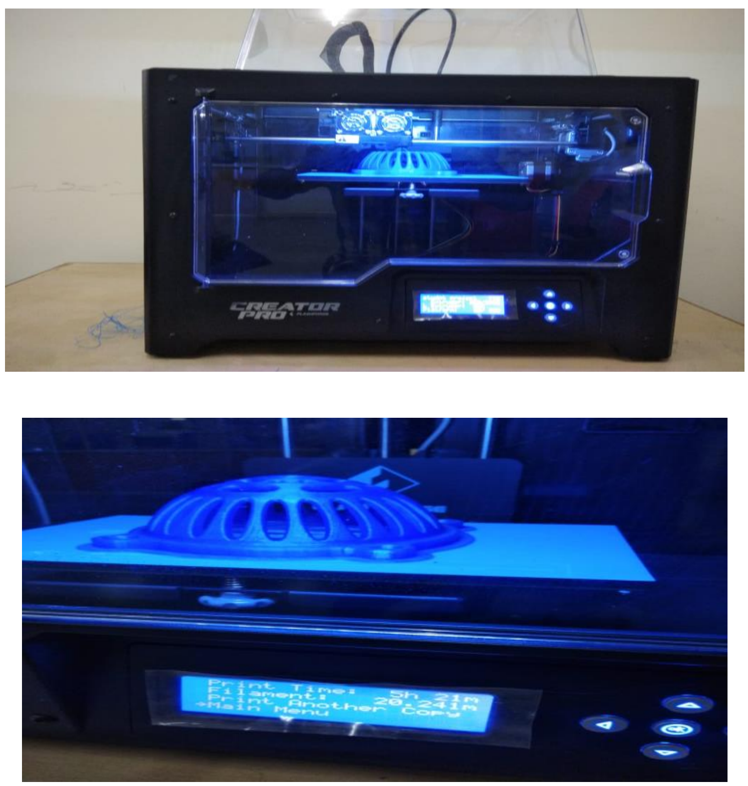
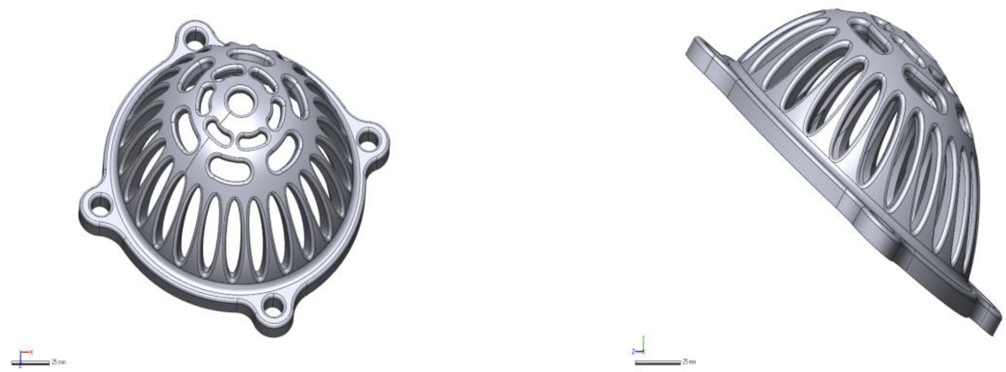


Figure 3.8 3D printed prototype

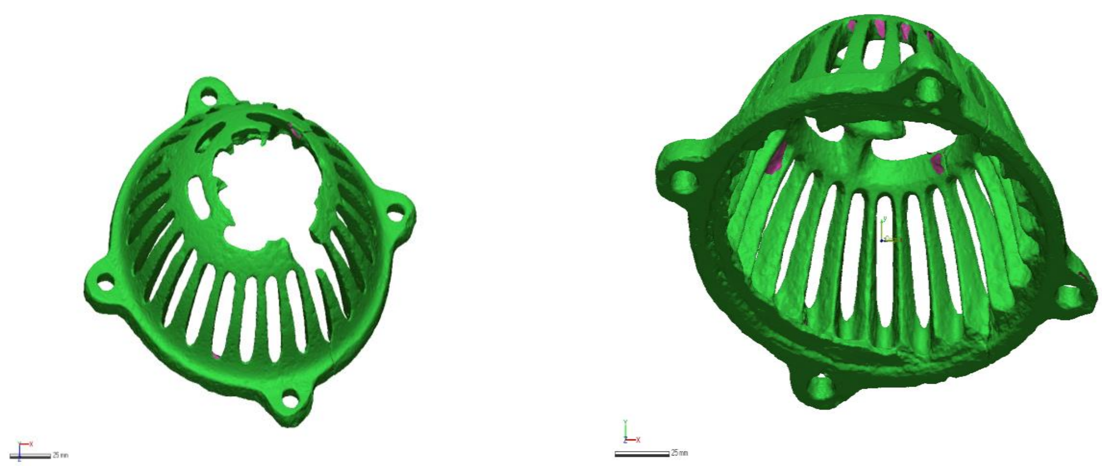
Chapter-IV

Results and discussion

The reference part as shown in figure 4.1 (a) in comparison with CAD model as shown in figure 4.1 (b) is aligned together to assess the deviation in order to ensure the manufacturability of the part earlier in the design phase.



(a)

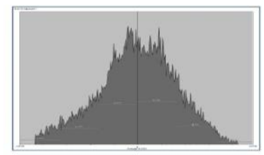


(b)

Figure 4.1 (a) CAD model (b) Original

The alignment that is preferred for the comparison of the part are shown in figure 4.2

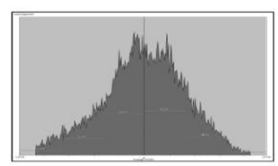
Result Data - 1 : Best Fit Alignment1



Min.	-2.2617
Max.	2.2615
Avg.	0.0103
RMS	0.8699
Std. Dev.	0.8698
Var.	0.7566
+Avg.	0.6865
-Avg.	-0.7077

Product Name	[Product Name]	Department	[Department]	Date	Apr 16, 2019
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Result Data - 1 : Initial Alignment1

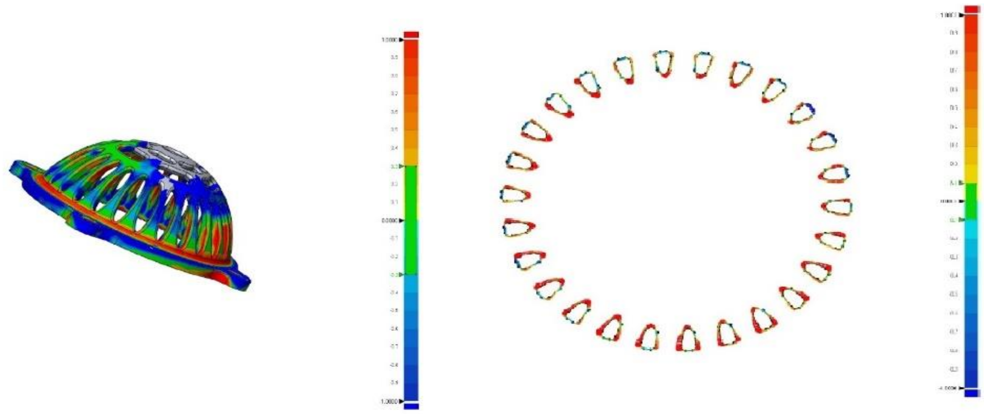


Min.	-2.2617
Max.	2.2615
Avg.	0.0103
RMS	0.8699
Std. Dev.	0.8698
Var.	0.7566
+Avg.	0.6865
-Avg.	-0.7077

Product Name	[Product Name]	Department	[Department]	Date	Apr 16, 2019
Part Name	[Part Name]	Inspector	[Inspector]	Unit	mm

Figure 4.2 Best fit and initial alignment

The maximum deviation we got for best fit and initial fit alignment is -2.2617 and minimum deviation is 2.2615. Also showing the same standard deviation of 0.8699.



Min.	-7.1586
Max.	7.1505
Avg.	-0.3196
RMS	1.5462
Std. Dev.	1.5128
Var.	2.2885
+Avg.	0.7466
-Avg.	-1.2649
In Tol.(%)	24.0906
Out Tol.(%)	75.9094
Over Tol.(%)	35.4452
Under Tol.(%)	40.4642

Min.	-2.6644
Max.	2.1289
Avg.	0.6097
RMS	0.8599
Std. Dev.	0.6064
Var.	0.3677
+Avg.	0.78
-Avg.	-0.3246
In Tol.(%)	7.3457
Out Tol.(%)	92.6543
Over Tol.(%)	80.0982
Under Tol.(%)	12.5561

Figure 4.3 3D and 2D comparison

Here the comparison is done for both 3D and 2D, Units are in "mm "and the deformation in the material is shown with the colour indicated in figure 4.3. The red colour indicates The Maximum deviation and blue colour indicates the minimum deviation. The maximum and minimum deviation in 3D compare is ±7.1505mm and standard deviation as

1.5128mm. where as in 2D compare the maximum and minimum deviation is ±2.6644 while standard deviation is 0.6064.In case of 3d compare the initial tolerance is 24.0906% and outer tolerance is 75.9094% and for 2D compare the inner tolerance is 7.3457% whereas outer tolerance 92.6543%.When compared to the original CAD file 40.4642% under tolerance and over tolerance 35.445% In 3D compare, For 2D the under tolerance is 12.5561% and over tolerance is 80.0982%.

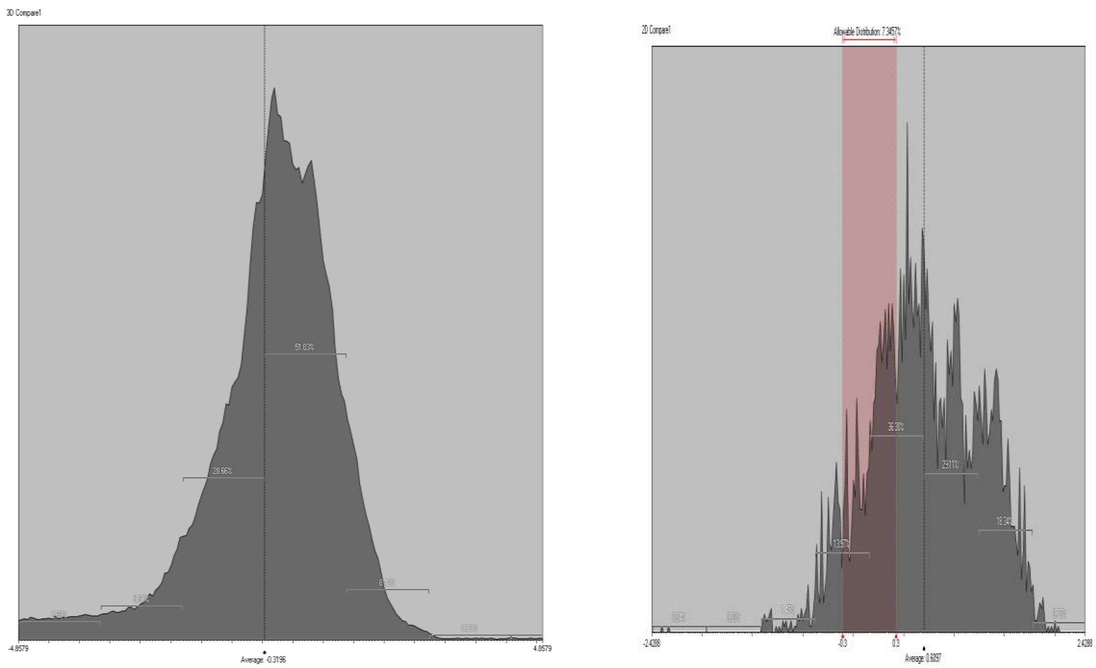


Figure 4.4 Deviation distribution curve of 3D and 2D compare

The deviation distribution curve as shown in figure 4.4 gives the average value of distribution +0.7466 and -1.2649 for 3D where as +0.78 and -0.3246 for 2D. Finally the deviation we got in both 3D and 2D compare is ±1 which is negligible and can be recommended for manufacturing.

Chapter-V

Conclusion

Conclusion

In adoption to new technologies for optimizing the production cost of industry these reverse engineering and additive prototyping method will be the best preferred approach. As it need not have to move towards formal way of designing from initial which is the difficult task, but to have the old one which had its own data acquired in software from which one can reconstruct easily using the modeling tools. These report gives the clear idea how the reverse engineering is used step by step. It also gives the information about the scanning method and performance. By utilizing the reverse engineering software also makes the reader learning the construction tools that are going to be applied. In addition, it also gives the knowledge of file format used for the reverse engineering and additive protyping. However, in many instances, it may lose small details if it goes directly into a STL file.

The 3D printed part and the original part was compared in order to check whether there is any dimensional errors that is to be notice. Both technologies are thus linked together that makes benefit not only to a manufacturing industry but also pharma, medical etc many more. Arranging the point cloud data automatically during scanning and printing by high alloy steel is recommend for future work.

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