New Frontiers in Manufacturing Education: Rapid Prototyping, 3D Scanning and Reverse Engineering

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Abstract –With the introduction of the first Rapid Prototyping machine two decades ago, manufacturing technology has matured from building prototypes by various additive processes to creating net shape finished product from CAD models and reverse engineer parts from data obtained from 3D scanners where no CAD models exists. As 3D scanners have been more affordable, the process of reverse engineering has become more common place adaptable to a larger number of manufacturing applications. Rapid Prototyping was first established at Albany State University with the purchase of a 3D Printer and SolidWorks CAD software in 2003. Since the summer of 2007, two different 3D scanners and complementing reverse engineering software were acquired. This fully functional reverse engineering facility is now used for conducting engineering student's research projects. A new laboratory project on 3D scanning and reverse engineering was added in the fall 2008 semester to the sophomore level introductory engineering course.

Keywords: Rapid Prototyping, 3D Scanning, Reverse Engineering

INTRODUCTION

Throughout the years advances in manufacturing technology has made it possible to transform the ideas to reality in virtually every field of science and engineering. With the introduction of computer aided design and manufacturing in the later part of last century, Engineers were able to build parts more precisely in significantly less time and cost. During the last two decades, a new class of manufacturing technology in the form of various additive processes has gained favor among engineers specifically to make prototypes that has shortened the product development cycle from months to weeks. Collectively known as Rapid Prototyping (RP) [1], it has now matured from building prototypes to check form and fit to create durable net shape finished product from CAD models and reverse engineer parts from data obtained from 3D scanners where no CAD model exist. Because of the far reaching influence of this new technology in different fields of manufacturing from medical devices to one of a kind or obsolete parts, it is deemed necessary that engineering students should be exposed to these novel forms of manufacturing in their early years of education. As a result after a detailed assessment [2] of various tools available today, students at Albany State University are introduced to this revolutionary technology through a laboratory team project in a newly established fully functional reverse engineering facility.

RAPID PROTOTYPING

The first Rapid Prototyping machine SLA -1 was developed by 3D Systems in 1987 which was based on stereolithography. Since then a large number of companies have come up with a host of RP machines based on other processes such as Selective Laser Sintering, Fused Deposition Modeling, Powder-Binder Printing. Though all of them are additive processes, the methods of manufacturing significantly differ amongst them as is the cost, surface finish and durability of the completed product. The principle behind the RP technology is that a thermoplastic resin powder can be sintered to a solid part layer by layer by sketching with a laser beam driven by coordinates created by the part's CAD model.

In 1996, the first 3D printer, based on powder binder printing was developed by Z Corporation bringing the technology to the office environment. No bigger than a copier, this class of printer broke the speed and cost barrier in RP technology. Subsequently other companies such as Stratasys and 3D systems came up with their models. Albany State University (ASU) operates a Dimension 3D printer, built by Stratasys, that is based on fused deposition modeling.

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Figure 1. Dimension 3D Printer from Stratasys and prototype of F-16 aircraft

The RP part construction differs from conventional machining in two ways. First material is added not removed. Second, RP systems start building up from the lowermost layer of material and then stack additional layers on top. In general all RP systems use the CAD model generated in STL (stereolithography) file format to drive the laser tool in its path. STL is a neutral file format designed such that any CAD system can feed data to any RP system. As such most 3D scanning and reverse engineering software also use STL as input and output format beside such popular formats as IGES, DXF.

Various steps in building the model in a RP system are: STL file generation, file verification, build file creation, part construction and cleaning and finishing. With the exception of the last step, cleaning and finishing, the whole process is completely automated and require no attention. Cleaning is the most frustrating and labor intensive part of the RP process which is dependent on the type of the machine used and frequently takes a significant fraction of the total time to make the finished part.

Finishing is mostly used if the part is needed as a showpiece for customer evaluation. The downside of RP manufacturing is that it takes significantly more time than conventional machining. A medium size part (8” x 6”) may take anywhere from 5 to 15 hours depending on the part and support’s internal structure and the orientation of the part.

IMPORTANCE OF 3D SCANNING

The CAD model needed to drive the RP machine is generally created with commercial CAD software such as SolidWorks, SolidEdge, AutoCAD Inventor, Pro-Engineer. This is possible when dimensional data are readily available. However, for obsolete one of a kind part for which no data are available or unwillingness of supply from original parts manufacturer or object with an organic form, geometrical data may by generated by recording the coordinates on the surface of the object at various points by Coordinate Measuring Machine [3]. This procedure is time intensive and prone to measurement errors. With the availability of affordable 3D scanner, the geometrical data can easily be recorded by scanning the object with a laser beam multiple times from different angles and subsequently aligning them with a software to create 3 dimensional object definition in a variety of file format. A large number of 3D scanners are available today designed for wide variety of purposes with varying degree of accuracy and cost.

Following are a few representative 3D scanners available today that are sold for under $50,000:

(a) NextEngine scanners from NextEngine Inc.
(b) E-Scan from 3D Digital Corporation
(c) FastScan from Polhemus
(d) Handyscan from Creaform

NextEngine [4] is probably the least expensive scanner available today. It has a very small foot print, not much bigger than an oversized cereal box. It captures 3D objects in full color with multilaser precision. Originally the

objects that can be scanned were limited to about 6” in length but the newer version is capable of handling larger objects of about 10” in the wide mode. ScanStudio Core software supplied free with the scanner scans, aligns, polishes and merges the point cloud data to form the model that can be exported in many formats including STL. Alongside this, there is also a plug-in that works directly with the ScanTo3D application within SolidWorks 2007 Office Premium. Accessories for holding the object upright is one of the unique features sold with the scanner. Educational price is only $ 2295 making it probably the least expensive scanners with acceptable resolution. RapidWorks, a version of RapidForm reverse engineering software, is also available for an additional $ 1995 (educational price) making it a very cost effective investment.

E-Scan [5] introduced in 2007 by 3D Digital is similar to NextEngine and scans objects from about one to two feet away. Laser beam sweeps over the stationary object to obtain the point cloud data. 3d Shape supplied software, SLIM aligns, merges, fills holes and remove noise to form 3D model that can be exported in many formats including STL. Both NextEngine and E- Scan require manual editing of unwanted data that may poses a challenge for beginning level users. Manual intervention may be necessary while aligning successive scans for both the scanners. Main advantage of E-Scan over the comparably priced scanners such as NextEngine is that the accuracy is better and there is no set object size limitation that can be scanned, though 8” to 10” in length may be ideal. Also, time to scan an object is significantly shorter in E-Scan making it easier to scan live objects such as facescan of people. Educational price for the E-Scan with SLIM software is $ 5000.

The last two scanners mentioned belong to a different class and are significantly more expensive. FastScan from Polhemus [6] and Handyscan from Creaform [7], both are handheld, self-positioning, portable devices that can be carried in a briefcase for scanning any object on site. Both these devices instantly acquire three dimensional surface images by sweeping the handheld laser scanning wand over an object in a manner similar to spray painting. The objects image instantly appears on the computer screen. As they provide real time visual feedback, monitoring and controlling the scanning process is straightforward. Handyscan also is capable of generating real time STL files thus eliminating the need for point cloud processing. Neither scanner requires cleaning unwanted data or aligning / merging the scans manually thereby saving considerable time and effort. The cost varies from 20000 to 40000 for educational institutions depending on the vendor and the specific scanner selected.

SIGNIFICANCE OF REVERSE ENGINEERING

Reverse engineering may be defined as the process of taking the finished product and reconstructing the design data in a format from which new parts or molds can be produced. The steps involved in a reverse engineering process can be classified as: obtaining and analyzing the dimensional data, creating the CAD model and transforming it into a prototype which can be checked against dimensional and functional requirements or improved further for new application.

When a 3D scanner is used to gather the dimensional data, the goals of a reverse engineering project will be:

1) Align and merge the scans to form one whole solid object
2) Refine and process the data further to fill the holes and patch any irregularity in the surface to make a complete, watertight STL file
3) Fit a surface through the scanned part data to create a NURBS model
4) Create parametric solid/surface model and transfer that to SolidWorks or another CAD software such that the original part geometry can be extended to create new model

Although a number of commercial reverse engineering software are currently available that varies in their ability to perform some or all of the steps outlined above, only two are discussed in detail here.

LeiosMesh [8]

The software imports point clouds data obtained with the 3D scanners or touch probes and transforms that into mathematical meshes or NURBS. Models can also be created using builtin parametric modeling tools. Extensive editing of curves and meshes makes model refinement possible including noise cleaning, smoothening plane surface or fitting a perfect cylinder over a curved surface, bridging mesh gaps and mesh hole filling. Model history is displayed in a tree like structure as in SolidWorks. Software supports most popular formats including STL. Single user educational price is $800 with an additional $200 for hardlock device enabling floating operations in any computer

Rapidform [9]

This standalone software performs all the steps outlined above for a true reverse engineering software, from aligning/merging the scanned data, patching up holes and fixing irregularities, aligning to a set of coordinate axis, creating a NURBS surface (Autosurfacing) model and exporting to SolidWorks as a parametric solid or surface model where it can be further extended by the normal tools available in SolidWorks. The software can import and export in all popular formats including STL. This is arguably the best and most complete software for reverse engineering and as such relatively complex requiring significant amount of initial training. This is also the most expensive software with a price of $20,000 per seat. But educational institutions can obtain a 30 seat floating license for $10,000 that can possibly be negotiated. The RapidWorks version sold bundled with NextEngine scanner is available for $1995 (educational price), but will only work with the files created in that scanner.

ENGINEERING PROGRAM AT ALBANY STATE UNIVERSITY

Albany State University conducts the Regents Engineering Transfer Program (2+2) and Dual Degree Program (3+2) to transfer students to Georgia Institute of Technology under a cooperative agreement. ASU students complete the core courses in humanities, science and mathematics as well as some freshman and sophomore level engineering courses such as Engineering Graphics, Engineering Computing, Introduction to Engineering Materials, Electric Circuits, Engineering Statics etc, in order to have a seamless transfer to junior level at Georgia Tech. ASU students are also required to enroll in a introductory level engineering course called “Principles of Engineering Analysis and Design” taught in the third semester with Pre-calculus as a prerequisite. The course is similar to the Introduction to Engineering course taught in virtually every engineering department and covers such topics as career opportunities, survival skills, team work, communications, and ethical practices. Our course also reinforce the concepts learned in Algebra and Precalculus with brief exposure to differentiation and integration, linear algebra, complex variables and application oriented problem solving.

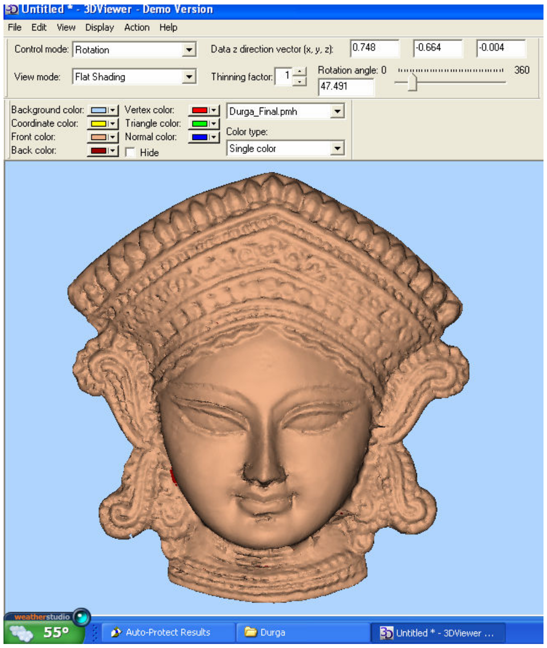
But the main difference of this course with similar courses taught elsewhere is a number of laboratory projects students are required to perform. The laboratory was established in 2001 with an original funding from the Department of Education and an intent to provide more realism and familiarity with the current manufacturing and testing equipment. The laboratory [10] comprises of a set of Lego RoboLab and NXT programmable robots, a CNC lathe, a computer controlled wind tunnel, a universal testing machine, a metallurgical microscope, a 3D Printer and MATLAB and SolidWorks CAD software. As is evident from the list of the equipment, an attempt was made to expose students to realistic and engaging learning experience by making them perform a wide variety of experiments and in so doing challenge themselves to engage in critical thinking in the underlying hypothesis of those experiments.

3D SCANNERS AND REVERSE ENGINEERING SET UP AT ASU

As mentioned above, Rapid Prototyping was first established at ASU in the form of a 3D Printer from Stratysis and SolidWorks CAD software in 2003. Primarily used by students to complete their CAD projects in Engineering Graphics course, SolidWorks is also used to introduce concepts of engineering drawing to high school students during Saturday Engineering Workshops. In both instances 3D part drawings made in SolidWorks are converted to prototypes in the 3D Printer to check the physical shape of the object.

When the decision to incorporate reverse engineering capability was taken, an extensive search of affordable 3D scanners and reverse engineering software were undertaken. With limited funding available, the search was restricted to the hardware / software combination available for under $10,000. Because of better resolution, no apparent limitation on size and quick scanning capability, 3D Digital Corporation’s E-Scan was chosen to be the first 3D scanner acquired in the summer of 2007. Also, LeiosMesh software was bought during the end of 2007 when the need for fixing the irregularities and patching up holes to create watertight STL model was urgently felt. The combination of E-Scan, merging/aligning software SLIM (supplied with E-Scan) and LeiosMesh were used to create a host of models for about a year. In order to create a true reverse engineering capability at ASU with a moderate funding level, NextEngine scanner and RapidWorks software were acquired during the summer of 2008. In spite of the complexity of RapidWorks software, significant level of competence has been achieved in mastering the nuances as is evident by the quality of the projects completed by the faculty and students so far.

RESULTS OBTAINED



After the initial break in period that is customary with any new software or hardware, the first completed project in the E-Scan, SLIM and LeiosMesh software was the recreation of a clay model of an icon. A total of eight scans were taken in building the model with hardly any irregularity other than a few small holes which were quickly patched up by LeiosMesh. The model was also printed in our 3D printer. Subsequently two more models, the Y-bracket and the Hammer, were developed and printed using the same scanner and software. Significant amount of missing scan data had to be regenerated using LeiosMesh after aligning and merging the initial scans for both projects.

Figure 2. Screenshot of the 3D Model of the clay icon

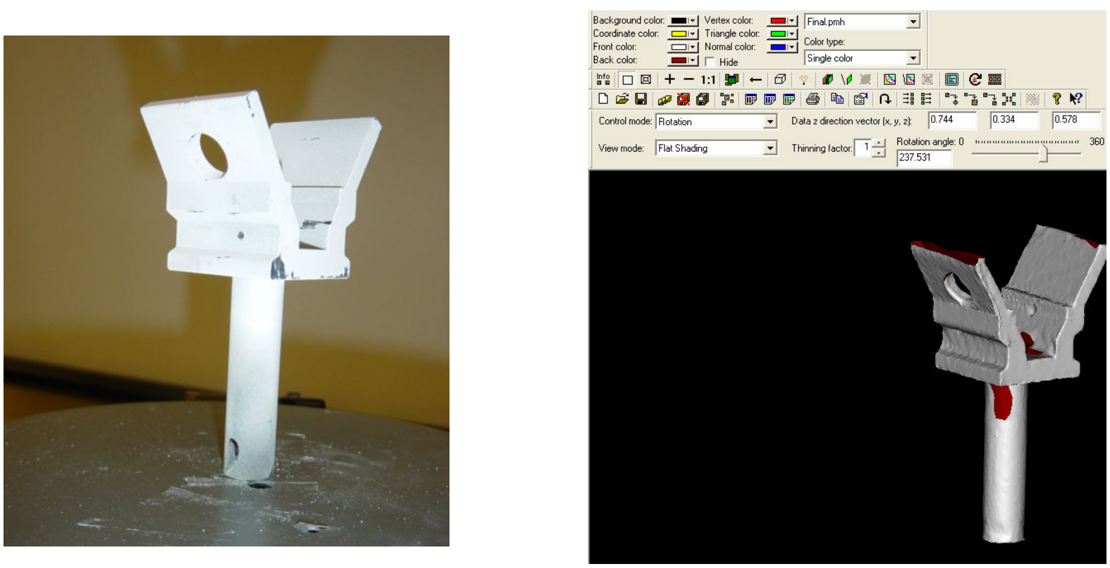


Figure 3. The original and screenshot of the 3D model of the bracket. Note the large patch of missing data before repairing with LeiosMesh

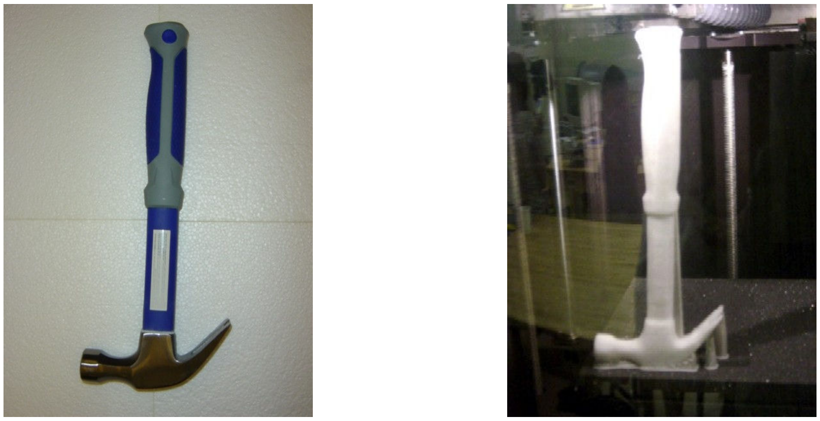
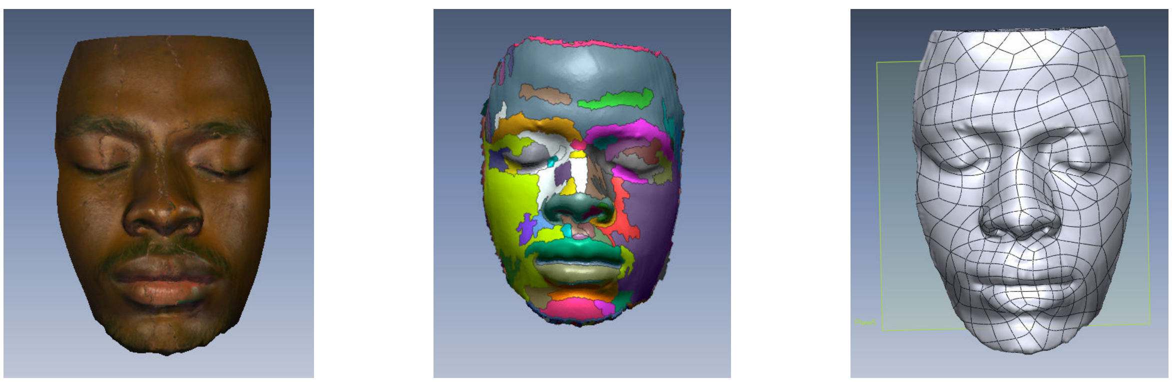
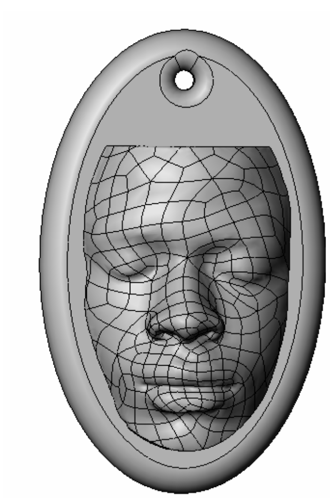


Figure 4. Original and prototype of a hammer inside the build chamber of the 3D Printer

Since the acquisition of the NextEngine scanner and the RapidWorks reverse engineering software in last summer a number of projects have been attempted. The earliest and most noteworthy of these projects that resulted in successful transition from scanned data to parametric model in SolidWorks has been shown in detail here. The first row shows, from the left, the scanned and aligned model obtained by scanning face of one of our engineering students in full color and texture, next one shows individual scans that were used in multicolor and the last one is the NURBS surface model.





The figure in the left shows the addition of the backplate after the surface model has been transferred to SolidWorks. The figure in the right is the prototype made in the 3D Printer.

Figure 5. Workflow of the Facescan Reverse Engineering Project

LABORATORY PROJECT

Inspired by the success of our attempt in establishing a reverse engineering facility at ASU, a new laboratory project was assigned to the students of the sophomore level course, "Principles of Engineering Analysis and Design" during the just concluded fall semester. In order to make the project more interesting and personal, each of the 2 member teams had to scan their teammate's face and have to go through the process of aligning/merging the scans, fixing holes, repairing the mesh model, and finally create a watertight solid by closing the back of the face by a plane. Three teams used the E-Scan and LeiosMesh and the other three teams used the NextEngine and RapidWorks. Students were allotted four weeks to complete their tasks. Because of the need to use the equipment for extended period as well as limited availability, the students had to work outside their normal laboratory class hours and reserve their time with particular equipment beforehand. One of the students was trained in RapidWorks earlier and acted as a resource for the others. The students also had to submit a written report on the project in order to get credit. All the groups could complete their projects on time though the quality of their work varied significantly. Two of the better models, one made by E-Scan / LeiosMesh (shown above) and the other by NextEngine / RapidWorks were made to prototype in the 3D Printer.

CONCLUSION

After going through a long process of searching different hardware and software tools available today, a fully functional reverse engineering facility has been established at Albany State University. For over an year and half, working in different projects with both of our scanners, a fairly high degree of confidence have been achieved in handling progressively more complex jobs in 3D scanning and reverse engineering.

This new technology has already shown to have profound impact in every discipline wherever manufacturing is involved. At ASU, incorporation of the reverse engineering project at the sophomore level introductory engineering course has allowed students for the first time to think in terms of modern manufacturing methods. Without a doubt inclusion of this project in the laboratory component of the Principles of Engineering course has satisfied the primary objective of providing students with increased familiarity in current trend in manufacturing processes.

A survey questionnaire administered at the end of the semester indicated that the students' overall perception of the project to be quite positive despite occasional scheduling problems. They were motivated enough to complete the job on time even though sometimes it required working in the weekend. It was heartening to see that the student teams took ownership of their work and display pride in their accomplishment by competing against one another to get the "best" job done.

As many different laboratory projects competes for a shrinking pool of capital equipment funding available, arguably this technology may hold a higher priority in providing the best return of investment in terms of preparing students ready for today's engineering market place. This is particularly true as 3D scanners and software become more readily available and affordable.

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Atin Sinha received his Ph.D. from the University of Tennessee Space Institute in Aerospace Engineering in 1984 and worked in Learjet and Honeywell before moving to academia. He joined the Albany State University in 1999 as coordinator of the transfer engineering program and teaches freshman and sophomore level courses in engineering. His current research interest is rapid prototyping and reverse engineering. He is also engaged in motivating students in inquiry based learning in engineering problem solving through laboratory experimentations. He is a licensed professional engineer.