AC 2008-992: PRELIMINARY ASSESSMENT OF DIFFERENT 3D SCANNING AND REVERSE ENGINEERING TOOLS FOR UNDERGRADUATE PROJECTS

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Preliminary Assessment of Different 3D Scanning and Reverse Engineering Tools for Undergraduate Projects

Abstract

With the availability of affordable 3D scanners the process of reverse engineering has become more readily adaptable to a large number of manufacturing applications from medical devices to reconstruction of obsolete parts. The process constitutes of scanning the object, cleaning and merging the scans, patching holes to create 3D computer model, subsequently resizing or redesigning the part in a CAD environment before constructing the prototype. In order to introduce students to this emerging technology, the procedural steps are currently being worked out to introduce one or more undergraduate projects at a sophomore level engineering course with a new system consisting of 3D scanner, software, CAD tools and 3D printer.

Introduction

During the last two decades, a collection of technologies known as Rapid Prototyping[1] (RP) has evolved into a mature alternative form of manufacturing that has made significant inroad into various fields. In RP a physical part is created by an additive process driven by solid model definition created by CAD software. The RP technologies, Stereolithography, Selective Laser Sintering, Fused Deposition Modeling, Powder Binder Printing, vary in their choice of materials and processes as in cost and durability of the finished part. However, all RP technologies have significantly shorten the product development cycle from months to weeks by eliminating mold making, casting, finishing processes and directly develop the prototype for concept modeling, form and fit checking, functional testing etc. A new technology with more far reaching impact is emerging in the last few years which can generally be categorized as Reverse Engineering.

What is Reverse Engineering?

Reverse engineering has been defined by the Society of Manufacturing Engineers (SME) as the process of taking a 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 requirement or improved further for new application. Traditionally reverse engineering can be performed by first creating a true 3D computer model in a CAD software such as SolidWorks, SolidEdge, Pro-Engineer etc. from the geometrical data obtained from the real life object by visual observation and direct measurement and then making the prototype. A process of reproducing a part for which no engineering drawing existed from data collected from Coordinate Measuring Machine to create computer definition that was fed into the CAD/CAM system has been described in the 1989 SME publication[2].

A more recent technological innovation has made it possible for obtaining the geometrical data directly from a real life object by scanning it with a laser beam. Though there are fundamental differences among the 3-D scanners made by different manufacturers, all of them first make multiple scans (up to 10 or more) of the solid object from different angles and align them with

the help of a software to produce three dimensional object definition in the computer in a variety of file formats. One of the most widely acceptable formats is STL that can be used to build a prototype[3] in a RP machine. In true Reverse Engineering, the software also should be capable of rebuilding the object in a format that can be further edited in conventional CAD software to provide extension of the original design. As such, a 3-D scanner, software tools and a RP machine are the components necessary to have the reverse engineering capability.
The most common applications of reverse engineering are replacement of obsolete or worn out parts, nonavailability or unwillingness of supply from original parts manufacturer, extension of original design for new application, cataloging of one of a kind object, medical devices (dentures, prosthetics) etc.

Scope of the Present Work

Albany State University conducts a transfer engineering program where students complete course requirements in humanities, social sciences and sciences before matriculating to Georgia Institute of Technology to complete the last two years of their degree program under a cooperative agreement. Students also enroll in several of the core engineering courses required in their respective major areas such as Engineering Graphics, Mechanics, Material Sciences, Electric Circuits etc.

In an effort to introduce more realism and familiarity with the current manufacturing and testing equipment at an early stage of students' engineering education, an Engineering Laboratory was set up during 2002 – 2003 from a grant from the Department of Education. The laboratory consists of a set of Lego-Mindstorm robots, FLOTEK 1440 wind tunnel, PC Turn 55 CNC machine, Tinius Olsen Universal Testing Machine, Dimension 3D Printer, and an Axiovert 40 MAT metallurgical microscope. 35 seats of MATLAB and 20 seats of SolidWorks CAD software are also part of the laboratory which is primarily used in support of the lab component of a sophomore level introductory engineering course called "Principles of Engineering Analysis and Design". The lab is also used for undergraduate research by our students and for conducting workshops for high and middle school students as part of the university's outreach program.

Because of the far reaching potential of this new trend in manufacturing technology, educators have attempted to introduce high and middle school students to be aware of advanced methods by building prototypes[4] as well as university students to reconstruct an object[5] through hands-on exposure in reverse engineering projects in their curriculum. With a view to provide our students also to experience the benefits of reverse engineering and utilize the full capability of the Dimension 3D Printer and SolidWorks software, it was decided to acquire a 3D laser scanner to establish a complete reverse engineering procedure. The goal of our effort is to identify one or more projects where students will first scan the object multiple times, clean the unwanted data, align and merge the scans to form a watertight model if necessary by filling holes, import it into SolidWorks to extend the original design as directed and then make the prototype in the 3D Printer. Once the entire set up is tested and the projects identified, they can be introduced in the "Principles of Engineering Analysis & Design" course.

Different Hardware and Software Tools

As mentioned earlier Albany State University already has a Dimension 3D Printer and multi-seat license of SolidWorks CAD software. In our effort to establish a reverse engineering capability, following 3D scanners and reverse engineering software were evaluated in terms of performance, ease of use and above all cost.

a) 3D Scanners:

i) NextEngine Scanner[6] from NextEngine Inc.

This equipment is one of the least expensive 3D scanners for beginning level users available today. The scanner is housed in a box with very small footprint. It captures 3D objects in full color with multilaser precision. 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. The only significant limitation is that the object should not exceed about 6" in length. RapidWorks, a version of RapidForm reverse engineering software, is also available for an additional $ 1995 (educational price) making it a very cost effective investment.

ii) Roland LPX Series[7] from Roland DGA Corporation

Three different models are available for different size objects:

LPX 1200 – for objects up to 5" in diameter and 8" in length ($21995)

LPX 60 – for objects up to 8" in diameter and 12" high ($7995)

LPX 600 – for objects up to 10" in diameter and 16" high ($11995)

The objects are placed inside the scanner on the turntable allowing the scanner to combine rotary and plane scanning modes with the touch of a button. The LPX EZ Studio software supplied with the scanner automatically scans, fills holes, aligns, decimates and merges scanned data into a 3D model that can be exported in most popular format including STL. Point cloud data can also be directly used in the most current version of SolidWorks CAD software. The software supports polygon to NURB surface conversion and is equipped with surface editing tools.

The scanner's attractive desktop appearance at an affordable price (educational price is $6600 for LPX60), combined with the ease of use makes it one of the ideal 3D scanners for entry level users. Time saved in cleaning unwanted data and manual alignment of the scans is the major advantage of this scanner. Also, scan quality does not get affected by the room lighting. The primary limitation is that the object has to fit inside the scanner.

iii) FastScan[8] from Polhemus

This is probably the best 3D scanner available today at a mid-level price. FastSCAN is lightweight, portable scanner that can be carried in a briefcase and can be set up outdoor to scan objects onsite. FastSCAN instantly acquires three dimensional surface images by sweeping the handheld laser scanning wand over an object, in a manner similar to spray painting. FastSCAN works by projecting a fan of laser light on the object while the camera views the laser to record cross-sectional depth profiles. The object's image immediately appears on the computer screen. Because FastSCAN provides real-time visual feedback, monitoring and controlling the scan process is straightforward. Unlike many other scanners, FastSCAN neither needs cleaning unwanted data, nor aligning and merging the scans manually. The sweeps list enables turning individual sweeps on and off to facilitate optimizing the amount of data in the final output.

The software supplied with the scanner offers a full array of functions including image resizing, point of view shifting and more. The software also offers numerous scan processing features such as fine smoothening, which can be used prior to exporting the scan. 3D data can be exported to a host of popular 3D modeling, graphics and CAD programs.

Two different FastSCAN systems are available to accommodate varied scanning requirements and budgets. The Scorpion has two cameras, allowing for more detailed scans in fewer sweeps than the single-camera Cobra. While scanning an object, the dual cameras on the Scorpion wand view the laser from either side to record surface profiles of the object. Cost of the single camera system is $ 21500 and dual camera system is priced at $ 27500 with an additional 5% discount available for educational institutions.

iv) E Scan[9] from 3D-Digital Corporation

This portable scanner introduced in 2007 can be mounted on a tripod to scan objects from about one to two feet away. Laser beam sweeps over the stationary object to obtain the point cloud data. Unwanted data has to be manually edited out which sometimes poses a challenge. 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. Manual intervention may be necessary while aligning successive scans. Its main advantage over the comparably priced scanners (NextEngine and Roland) 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. Educational price for the E-Scan with SLIM software is $ 5000.

b) Reverse Engineering Software:

i) Rhinoceros[10]

This software connects with digitizers for capturing existing model geometry. Editing and aligning imported data is possible though most users choose a different program to do so. Manual interface is required for these operations. Third party vendor plug-in is available to import scanned data from NextEngine scanners. The models can be built using the regular geometric shapes or polysurfaces based on 3D curves directly in Rhino. The software can import and export in many popular formats including the most commonly used STL format needed for RP machines. However, the STL files would not show as a parametric model in SolidWorks and cannot be further edited. Additional plug-in software can be used to repair holes and gaps in the STL model to make it watertight before making the prototype in a RP machine.

The popularity of this software stems from the fact that it is by far the least expensive among all such software available currently. Educational price for the full version bundled software for single user is only $ 495, while license for 30 seats costs $ 2700. Educational price for single user for Rhino 4.0 alone costs only $ 195.

ii) Rapidform[11] XOR and XOS

The standalone software Rapidform XOR includes all the tools necessary to clean up and align imported scanned data from a variety of 3D scanners. Some manual interface will be required for these operations. Because of availability of integrated tools no external plug-ins are required. After preparing the scanned data, the software exports to SolidWorks and builds a parametric model that 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 pricey software with $10000 for 30 seat floating license that can be 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.

iii) Geomagic[12]

This is another powerful reverse engineering software that supports all leading 3D scanners and digitizers. Geomagic Studio captures point clouds, facilitates scan registration and converts polygon models into NURBS models. Plug-ins allow users directly control and manage data capture. Wrap feature of the software eliminates time consuming surface reconstruction by mathematically wrapping a polygon surface from point cloud data. User defined layout capabilities and interactive surface editing provide complete control over the output surface. Automated processing and user control for fine-tuning create watertight models to make the prototype in a RP machine. Software can import and export in all of the popular file formats including STL. Educational price for single user floating license is $6250 including maintenance for first year.

iv) LeiosMesh[13]
The software imports point clouds data obtained with the 3D scanners or touch probes and transforms 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, 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.

Reverse Engineering Projects at Albany State University

As mentioned previously, Dimension 3D Printer and SolidWorks CAD software are used regularly at Albany State University by our students in the Engineering Graphics course as well as high school students in the Engineering Workshops since 2003. When the decision of incorporating reverse engineering capability was taken, an extensive search of available yet affordable 3D scanners was undertaken. Without external funding, a quality scanner such as FastScan from Polhemus was ruled out. 3D Digital Corporation's E-Scan was acquired during the summer of 2007 primarily because of its affordable price, good accuracy and no limitation on objects size. Since then the scanner has been used extensively attempting to create 3D models of various small to mid-size objects with increasing level of success. It was discovered the hard way that in spite of claims of creating watertight models by the vendor, it is by no means guaranteed for beginning level users. Cleaning unwanted data and aligning multiple scans manually are two of the most annoying and frustrating problems encountered at least for this particular 3D scanner. Even when these problems were addressed, a clean watertight model without any holes could not be created. At this point a search for reverse engineering software was undertaken partly to address the problem of fixing the scanned model so that it can be converted into a solid part in 3D Printer and also to examine the possibility of exporting to SolidWorks for downstream application. After going through the information available in the web, attending webiner and trying out demo version of different software, it was discovered that perhaps Rapidform and possibly Geomagic can satisfy all the desired qualities of the required software. However as cost of either of these are significantly higher than our current budget, LeiosMesh was acquired in last December. It was quickly discovered that this software can fill holes no matter how large they may be. Holes can be filled either by flat surfaces or based on curvature. The software also is capable of fitting an analytical surface such as sphere, cylinder or plane through the scanned data.

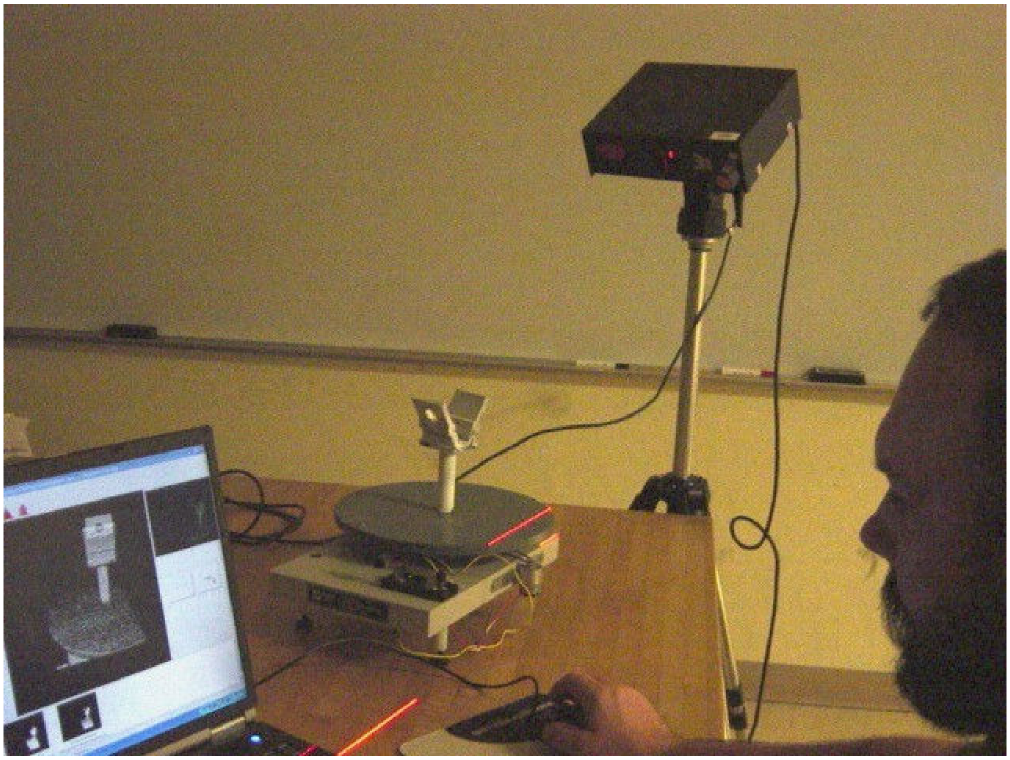

Figure 1. Object on a turntable being scanned by E-Scan 3D scanner

Figure 1. shows the set up to scan objects by E-Scan 3D scanner which is connected to the laptop computer with a USB cable. Results of the successful projects, with original objects and the prototype made in 3D printer are shown in the figures 2 and 3.

Figure 2. Original clay idol and prototype made in 3D Printer

Figure 3. Original hammer and prototype inside the build chamber of 3D Printer
(Note: small columns of support material to facilitate building process)

Lessons Learned and Future Challenges

Currently the process of 3D scanning and reverse engineering is still in the formative stage with a number of hardware and software vendors trying to establish their product in the market as the most effective solution for the customer needs. As is obvious, no single scanner or software is going to be the best fit for every application as they widely vary in their performance and cost. Also, it has been observed that 3D scanning is still more of an art than science as a number of factors determine the final outcome of the project. The following observations are made with a specific reference to E-Scan and Slim software bundle available from 3D digital Corp., but apply equally to most other products also.

a) Lighting in the room should be as low as possible
b) Surface texture of the object play a major role in scanning. Ideal object is matte and white, worst being black and shiny. The object must be coated with Magnaflux or similar spray if shiny or metallic to give it a matte, white texture.
c) Rounded objects will be easier to scan than objects with flat surfaces meeting at an angle.
d) Objects with features that include few distinctive reference points make the alignment of scans easier. Axysymmetric objects will require introduction of temporary reference points before scanning that have to be removed later.
e) Successive scans must include sufficient overlapping regions to ensure proper aligning and merging.
f) Cleaning up unwanted data require a steady hand.
g) Aligning successive scans require lot of practice and judgment in choosing the right aligning reference points if manual alignment is necessary.
h) Software should have the ability to fill holes manually as it is virtually impossible to eliminate holes in the final aligned and merged model.
i) Individual scanners restrict the size of the object to be scanned though one can scan successively part of the object and merge them together later.

j) Scanner resolution will determine the accuracy to which detail features are reproduced.

The next logical step in our quest to establish a fully functional reverse engineering capability is to import the solid model created from scanned data to SolidWorks CAD software which can then be manipulated for any of the downstream applications as specified by the design requirements. As mentioned earlier, a cost effective solution of this significantly challenging problem will be to use the NextEngine version of Rapidform software though it undoubtedly will involve a larger investment of time and effort.

Conclusion

The process of physical geometry capture to create the computer definition of any object at an affordable price was always manufacturing engineers dream. Today with the help of 3D scanning and RP machines, that dream is turning into reality in a number of industries. Experts use the term “Disruptive Technology”, which is when a technology changes how people work or live in a fairly short amount of time. This is usually achieved through new functionality or more commonly easier-to-use technology combined with dramatically lower cost of adoption. This is when a technology truly becomes “A Product” and typically will achieve mass market. Personal computers, World Wide Web, cell phones, GPS are all examples of Disruptive Technology. Perhaps reverse engineering has not yet reached that stage yet but one can be reasonably certain that its use will be felt more and more in a host of disciplines wherever manufacturing is involved.

After going through an extensive search of low to mid range hardware and software available in the current market, E-Scan and LeiosMesh were acquired to provide us with a functional reverse engineering capability. The details of the process of developing a prototype from direct scanning of an object, cleaning, merging the scanned data, patching holes or defects to create a water tight STL model to be printed in a 3D Printer are being worked out.

The primary objective of this effort is to introduce this breakthrough technology to the engineering students at an early stage of their education not only to motivate them towards continuing their studies but also provide them with a first hand opportunity of getting ready for the “real world”. Because of the time and effort needed to complete any reverse engineering project successfully, the assigned work may need to be performed by students working in two or three member teams outside the normal laboratory class hours. One possibility may be to assign the projects at the beginning of the semester after the introduction of the equipment and describing the procedure and then allowing the student teams to complete the work over an extended period of time at their own convenience.

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