AC 2010-106: TEACHING REVERSE ENGINEERING FOR NON-INDUSTRIAL APPLICATIONS

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Teaching Reverse Engineering for Non-Industrial Applications

Abstract

This paper focuses on teaching non-industrial applications of reverse engineering technology to engineering and non-engineering students. Manufacturing and mechanical engineering students as well as forensics minors studied three key elements in history preservation, medical and forensics applications in this Reverse Engineering and Rapid Prototyping course which is a senior-level engineering elective. Students scanned artifacts using Minolta 910 or Handy-Scan digitizers, prototyped their replicas with Fused Deposition Modeling based Dimension Elite or Stereolithography System Viper Machine, and make RTV molded copies of the artifacts by using the prototypes as patterns after reviewing a historical artifact preservation case study. They were also exposed to the medical virtual reconstruction area with demonstrations of a software tool called Mimics. Forensics exercises included a review of a skull and facial reconstruction study by an FBI expert and working with the Magics software. The details of each key element needed to be controlled due to busy course schedule that also covered manual NC and CAM based programming, rapid tooling and rapid manufacturing content.

Introduction

Reverse engineering has been utilized in the engineering world to learn from competitors' product designs in order to maintain competitive advantage against them. It should be conducted within the boundaries of ethics and intellectual property laws. On the contrary, reverse engineering concepts and tools have been commonly used in applications other than product development or industrial needs. It is employed by medical technologists, historians, anthropologists, paleontologists, primatologists, and forensics scientists, just to name a few professions.

Following a literature review summarizing relevant educational cases, this paper presents the key examples of non-industrial reverse engineering applications within a senior level manufacturing engineering elective, ENGR 4801 – Rapid Prototyping and Reverse Engineering. Other engineering majors and forensics minors can also take this course as a technical elective with the approval of their academic advisors. The ENGR 4801 is a 3 credit course, with two 50 minute lecture and one 2 and ½ hour laboratory time weekly. It is also offered as a graduate elective for the MS in Engineering Management program.

Literature Review

A literature review conducted by the authors indicated the various ways reverse engineering methodology and its tools utilized in engineering education. Following is a brief summary of the literature review. Goss presented a non-educational project where he used the CADKEY geometry generation engine along with his measurements to restore an antique windmill[1]. Kellogg and Jenison's students explored the engineering design process by dissecting a fabric shaver, a Dremel Free Wheeler, and a Kodak camera[2]. Jahan and Dusseau used water purification units to introduce concepts of reverse engineering to a multidisciplinary freshman class. The student teams of four to five studied the engineering principles behind the functions of the units as well as intellectual property rights, safety, ethics, ergonomics, and environmental issues in engineering design[3]. Newstetter and McCracken differentiated between the terms of reverse engineering and design recovery. They suggested instructors to teach design recovery, an activity of discovering processes employed in engineered artifacts, with the premise that design recovery was a means of understanding design skills[4]. Hess focused on solid modeling and reverse engineering as he synthesized manufacturing process and product development education [5,6]. Robertson, Wales, and Weihmeir used reverse engineering as a means to understand complex tool design for semiconductor processing[7]. Their class project was a self-paced 4-stage team activity that included classical reverse engineering dissection methods as well as the trade-offs in design decisions for functions and production volume. Forsman wrote about a senior level technical elective course for reverse engineering and rapid prototyping for mechanical engineering technology students where he employed some engineering methods in engineering problem solving and reverse engineering tools in measurements[8]. Orta, Medoza, Elizalde, and Guerra employed active learning methodologies including reverse engineering in experimental aircraft design where students learned by stepping backwards through the development process[9]. Shooter in his paper presented a 3-week module that was incorporated into an interdisciplinary introduction to engineering course[10]. The module employed product dissection and reverse engineering to teach students how to improve existing designs. Lecture and laboratories were complemented by podcasts guiding students through the product dissection process. Sinha prepared a comprehensive assessment of 3-D scanning and reverse engineering tools available for undergraduate engineering projects. His study also included the functionalities of the tools[11]. In a more recent study, Sinha integrated reverse engineering into a laboratory-based sophomore engineering course based-on engineering design and analysis[12]. Halsmer, Roman and Todd[13] applied a function-based reverse engineering approach to complex natural systems. The approach was designated to teach engineering students the impact of engineering on earth as well as biology, chemistry, physics, psychology, sociology, anthropology and a few other important subjects.

This limited literature review indicated multiple studies using product dissection or design recovery in teaching design or design improvements. Only a couple of studies focused on restoration or natural systems. Technologically based papers on hardware and software tools were also in minority. They are however found in technical conferences and periodicals.

ENGR 4801 Reverse Engineering and Rapid Prototyping Course

In the ENGR 4801 Reverse Engineering and Rapid Prototyping course, students start with the study of the intellectual property laws including patents, copyrights and trademarks. They learn details like the difference between copyright and patent issues as in the cases of making illegal copies of software tools and illegal utilization of software features in another software tool respectively. The early part of the course curriculum includes the reverse engineering methodology and its place in product development and competitiveness along with tools such as coordinate measurement machines (CMM) and 3-D scanners. It is followed by computer numerical control- and additive-based rapid prototyping subjects including fundamentals of rapid prototyping and its role in product development, rapid tooling, and rapid manufacturing. Manual and Mastercam based numerical code (NC) generation, operation of CNC machines and prototyping systems facilitate the hands-on elements of the course allowing students to gain practical experiences.

The reverse engineering content of the course also encompasses non-industrial fields such as history preservation, medical applications, and forensics. Students are exposed to uses of reverse engineering with historical artifact preservation, virtual and physical reconstruction of human limbs and skeleton, and forensic victim identification studies. All of these applications are imperative to prepare well-rounded engineers for non-industrial occupations.

The idea of preserving and replicating historical artifacts is not new. The development of 3-D computer scanning technologies has broadened the customers of reverse engineering to historians, anthropologists, paleontologists, primatologists, greatly enhancing tool arsenal available within these areas. In ENGR 4801, students are presented with a case study conducted on preserving historical artifacts [14]. The case study is about digitization and replication of a historical plaster pattern of Robert Morris (Figure 1), one of the founders of the United States of America. Details of the scanning stages (Figure 2) and engineering solutions developed for successful digitization such as fabrication of a rotary table and its introduction to the Geomagic scanning software are introduced within the study. The three rapid prototyping technologies that produced copies of the original piece are also discussed in detail (two of which are shown in Figure 3). Subsequently, the use of Room Temperature Vulcanization (RTV) molds to cast polyurethane copies is demonstrated (Figure 4). A detailed comparison for the three rapid prototyping technologies as well as producing polyurethane copies is provided in the concluding section of the case study.

Figure 1.The original artifact to be scanned

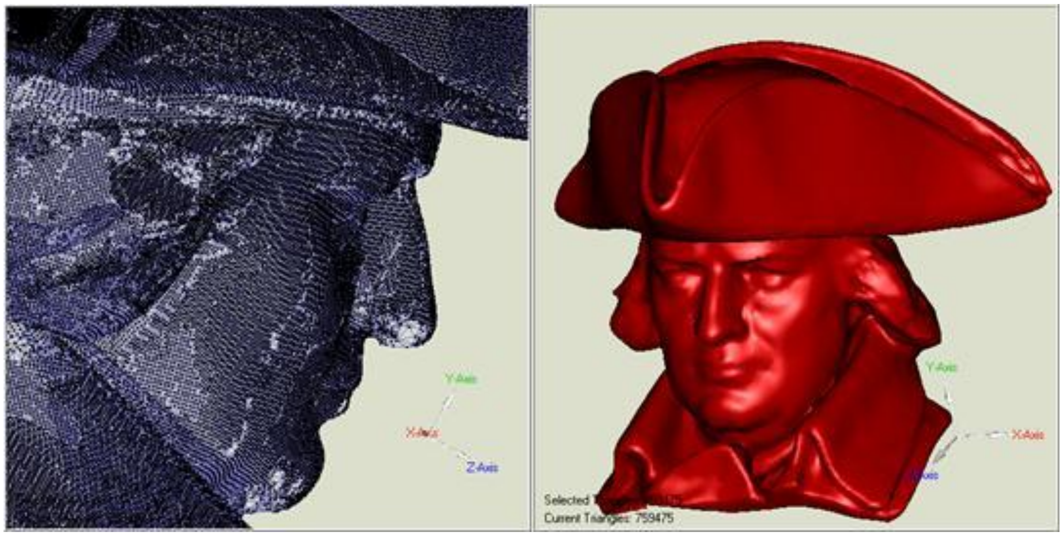

Figure 2. Polygon file obtained by the scanning process and the resulting STL file

ENGR 4801 students were first asked to review the case study. They were then asked to follow the four steps of the preservation process: (i) digitization of artifacts by scanning an object of their choice either by using the Minolta 910 camera or the Creaform's Handy- Scan (Figure 5), (ii) rapid prototyping replicas of the artifacts scanned - with the two options of the Dimension Elite or Viper SLA machine (Figure 6), (iii) fabrication of silicon rubber molds by using the replicas from the previous step or powder metal parts (Figure 6), (iv) making polyurethane replicas utilizing the silicon rubber molding process (Figure 6).

Figure 3. Rapid prototyped replicas of the original piece (Fused Deposition Modeling – left, 3D printing – right)

Figure 4. RTV molds halves and a polyurethane copy made by them

The virtual reconstruction was the second non-industrial element the students were exposed. For this course element, a two prong approach was applied. One was to utilize forensics field while the other one was on medical applications. The virtual reconstruction process starts with digitization of physical elements such as bone fragments of a primate or a crime victim. These digitized elements are manipulated by eliminating noise, filling in missing geometric data, and assembling them within the CAD environment. The next step beyond the virtual reconstruction is to realize the CAD model via rapid prototyping, or physical reconstruction. Another growing major application of the virtual reconstruction is the generation of custom implants or scaffolds for replacement of missing sections of human bones.

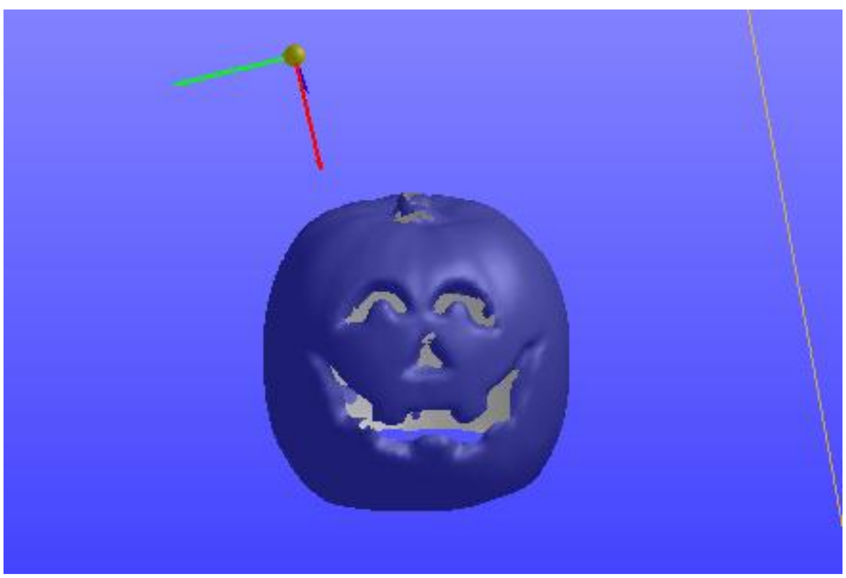

Figure 5. Scan conducted by a student using the Creaform's Handy-Scan scanner and VxScan Software

Figure 6. A rapid prototyped replica (left/front row), silicon rubber mold halves (back row) and their pattern (middle/back row), and the esulting polyurethane replica (right/front row)

In terms of the medical applications of virtual reconstruction, a demonstration on Materialise's Mimics software was conducted to show the students how medical imaging data was used. Students were shown multiple projects including a skull with a hole (Figure 7), a hip, and a knee model. They were informed about the other uses of Mimics software including medical education and training, pre-surgical planning, and biomedical engineering analysis through Finite Element Analysis (FEA). Mimics software allows engineers to transform 2-D Computerized Tomography and Magnetic Resonance Imaging (MRI) data to 3-D with good accuracy and flexibility. Users can take advantage of its segmentation tools to convert scanner data to a variety of output formats including STL, or perform a variety of design and engineering operations directly on the 3-D model[15].

Virtual reconstruction for forensics has been one of the growing application fields of reverse engineering, replacing the hard work of skull re-constructionists[16]. Students were given a paper written by Carl Adrian of FBI, who is a visual information specialist and examiner[17]. The paper goes through the skull and face reconstruction process explaining the conventional clay-based and new reverse engineering based-methods as well as the technology associated with them. Of the scanners covered in the paper, the engineering department owns the FARO arm as wells as the Minolta Camera. However, the paper also included PolyWorks and MAYA software tools which are not available at the department. Students were asked to review the paper and write a page and a half summary of it. Materialise Magic software was also utilized by the students for manipulating STL files and generating assemblies of them replicating the functions of PolyWorks and MAYA software tools.

In addition to the medical and forensics examples mentioned above, students had to write a 3 to 5 paper literature review paper on various subjects. Some of the students chose medical and forensic applications as their subject area. They used the university's electronic library including the research databases as well as the Internet search engines.

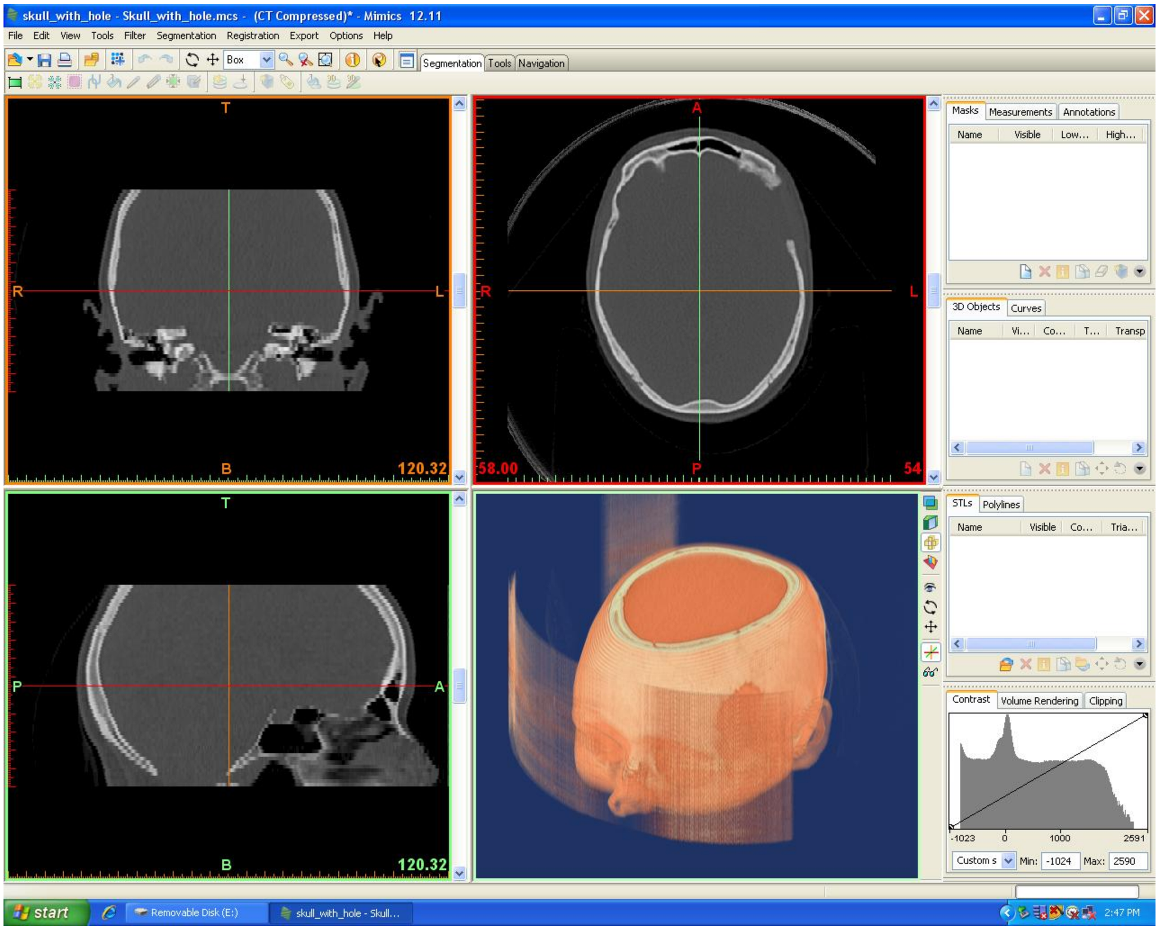

Figure 7. An example Mimics project – skull with a hole

Conclusions

Each of these three course elements in history preservation, medicine, and forensics presents the students with detailed information on the stages of the reverse engineering work and the data associated with them. Furthermore, the students were encouraged to utilize these reverse engineering tools and what they learned from these activities in their reverse engineering term projects. The responses from the students towards these elements were very positive. However, a few chose to learn additional content in each of these three areas. This can be explained by not having enough interest in these areas and having busy course schedules. The approach allowed manufacturing and mechanical engineering majors as well as non-engineering students to be exposed to state-of-the art equipment and software tools, and new methodologies to broaden their views. It will also lead to better preparation for future non-engineering jobs or projects.

Future work in the area will include development of additional laboratory exercises in medical and forensics fields as well as continuation of the activities described in this paper. Students will be given less CNC content since this is being added to the ENGR 3600 Production Engineering course which is the manufacturing processes course for the engineering department. The students will also be given a choice on working either medical or forensics projects to increase the depth of the exposure. Project presentations will allow all students to get exposure to the applications studied by the others in the class.

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