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Utilization of Freeware and Low Cost Tools in a Rapid Prototyping and Reverse Engineering Course

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Utilization of Freeware and Low-Cost Tools for Rapid Prototyping and Reverse Engineering Courses

Abstract

In this Rapid Prototyping and Reverse Engineering course, the rapid enrollment growth makes teaching more challenging due to having two sections with a total enrollment of eighty three students. The enrollment has increased from a single section of twenty four students in 2014 to its present condition.

Even though the Rapid Prototyping Laboratories are equipped with three FDM/FFF (UPrint SE, CubeX, CubeProDuo), two Powder-based (Prometal RXD and Projet 460plus), and one SLA (Projet 1200) printer, maintenance issues and time sharing of the equipment with other courses including the capstone projects reduce the availability of 3D printers. Therefore, multiple new machines including a Mendelmax and Prusa Mendel were built to utilize in the class. Since the SLA Viper machine was replaced with a Projet 1200, the old but comprehensive software tool of 3D Lightyear had to be replaced with new tools used for both processing of the STL files and printing. These new tools are easier to use but not as comprehensive as the old ones. Thus, a low-cost software such as Simplify3D was acquired and being prepared for teaching improved support generation through editing. On the other hand, the Reverse Engineering capabilities of the department include three scanners, a Konica/Minolta 910, a FARO Platinum arm, and a Creaform HandySCAN complemented with multiple perpetual Geomagic Studio licenses for data acquisition and handling. The department also have perpetual licenses for Mimics and 3-Matic, however it chose to replace the Magics software for STL file editing and manipulation with Meshlab and Meshmixer software which are freeware. This decision was made based on the outcome of a student project. In addition, the applications such as 123D Catch and Remake, both by AutoDESK are being employed for more 3D Scanning exposure. After the scan, students are able to send their still pictures taken by their smart phones to a cloud server for 3D image generation and then use Meshlab or Remake in handling the scan data by editing including removal of noise and undesired segments, patching of holes. Remake software can also prepare the scanned geometry for a set of commercial 3D printers available.

This paper details use of freeware and low-cost tools including the smart phone applications. These tools do not substitute the industrial 3D Printers or Scanners or their software, but allow greater number of students to be exposed to the current technologies in both fields. Upkeep of these tools are also free or comes with a very low-cost. However, the use of Rep-Rap machines is more challenging than desktop printers that lie within the $2K – 4K cost range and their associated quality. The paper will conclude with an analysis of student feedback and the impact of student learning with assessment of the ABET student learning outcomes.

Introduction

The rapid enrollment growth in this Rapid Prototyping and Reverse course made hands-on and practical components to be effectively delivered hard. Even though the laboratories of this department are equipped with a good number of 3D scanners including a FARO Arm and Creaform's HandySCAN and printers like 3D Systems Projet 460plus and 1200, and EXONE RXD as well as their associated software, they are no match to dozens of students who are interested in taking the course, along with other needs such as prototyping for course projects in Product and Tool Design, Design and Manufacturing of Biomedical Devices and Systems, and the capstone course, Integrated Engineering Design.

The instructor has started utilizing low-cost hardware tools including Rep-Raps such as Mendelmax and Prusa Mendel or 3D Systems Cube machines in 3D Printing and smart phones along with cloud-based 3D scanning software applications such 123D Catch and Remake both by AutoDESK and which are freeware.

Reverse Engineering

In an attempt to give additional opportunity for students to gain hands-on reverse engineering technology experience and associated skills, a two-fold approach was developed where a work-study student went through a 3D scanning experience using smart phones and cloud-based software to help develop new course materials while the students in the class were exposed to 3D scanning with 123D Catch. This reverse engineering technology content is in addition to the reverse engineering project student teams have to complete by usually studying a commercial toy through the reverse engineering methodology.

3D Scanning with Conventional Equipment and Smart Phones

Typical commercial 3D scanners involve either the use of a mobile laser source, camera and a software program in the case of a FARO arm or a still camera, turntable, and a software program in the case of Konica Minolta Vivid 910. Software programs make use of multiple scans from different angles to put together a 3D object. The Konica Minolta still camera and a turntable that rotates 4 degrees to provide 90 images for the software to use. A FARO arm uses both laser technology and a stylus for contact scans as well and is movable around the object. Laser technology in 3D scanning, specifically the hand-held type scanners, are based on the method of triangulation. The laser projects a line onto an object from the device and multiple sensors measure the distance to the surface and saves the data in an internal coordinate system. Once uploaded into software that reads the coordinate system, the object scanned can be reproduced electronically on the digital coordinate system in 3D form[1].

Smart phones are nearly universal now among the college student and contain an incredible array of tools and resources to help students in their courses. The phone cameras can have a role also as a low-cost 3D scanner when paired with a free modeling software such as MeshLab, AutoDESK ReMake, and mobile app 123D Catch, also by AutoDESK. These phones became a great tool to use in an engineering classroom setting for a small-size school such as this one because the student brings his or her phone to the classroom every day. The cameras that are used in these phones have evolved to produce similar quality images that can be seen from some lower cost digital cameras. Apple's iPhone 6, the main photographic device used for this project, has an 8-megapixel (MP) camera and has features that one would expect from a digital camera; automatic High-Dynamic-Range Imaging (HDRI) and digital image stabilization[2]. Models of the iPhone have made use of complementary metal oxide semiconductor (CMOS) to turn the light received by the camera into electrons. Using the electricity, the phone can turn the light into pixels and form an image. CMOS is typically cheaper and demands less power than the charged couple device (CCD)[3]. CCDs can be found in applications where higher image quality is demanded and more resources can be devoted to the processing of an image. Conventional 3D scanners such as the old Konica Minolta Vivid 910 has only 307 kilo pixels available for a fine scan, while a new version may have about 1.1MPs. The features of the iPhone camera meant that it would be more than capable of providing the images the project team needed in order to test the ability of the tool with the software in a classroom.

Cloud-based Scanning Software

AutoDESK provides the program 123D Catch for free on the app store of any device and ReMake for free for educational purposes. 123D Catch app does not have any editing feature but can be used with programs like Mesh Lab to generate complete scans resulting in watertight STLs. A premium version of ReMake exists which gives the user access to an "ultra" high definition 3D mesh instead of the "standard" lower definition mesh used for this experiment. ReMake, which can create high definition meshes, works by using the overlap of many images at different angles and stagnant backgrounds in order to form a mesh of the pictures by connecting common reference points. This is similar to the operation of still camera such as Konica Minolta Vivid 910. Digital image stabilization is an important feature of any smart phone camera because the background provides important reference points for the software to work with. By providing a stable focus with limited motion blur, the software can easily recognize matching images. The use of other reference points, such as the surface on which the object is placed, is important as well. The geometry of the mesh is formed by a plethora of triangles which can be manipulated once editing begins and re-topologized, sub-divided, and even decimated in order to finely edit parts. After the scan is topologized, it is ready for analysis and editing. ReMake provides a multitude of tools that can be used to prepare a mesh for 3D printing. Slice and fill cuts away any extraneous material around the part. For the purposes in this experiment, the team needed to only slice out the platform the object was set on to isolate the part we wanted to build. ReMake has tools available to smooth out surfaces or sculpt parts of surfaces. The surface can be precisely manipulated by changing the size of the brush, the brush being a major tool for editing, to either greatly affect the smoothness of a part or minutely finish a fillet on a corner. Other tools, such as bridge gap and fill holes are used to make the part ready for printing. Objects for 3D printing are made possible all by a simple cell phone camera and a free mesh-making software like ReMake, which can make up for any shortcomings brought on by an iPhone camera.

Experimentation

A number of different attempts at creating 3D meshes were done before a successful object had been scanned and could be printed with no problems[4]. During initial experimentation, objects were placed on a monochromatic table in a faculty office hallway with dim to moderate lighting. 36 pictures were taken and saved into the cloud based queue that ReMake[5] uses to create models via their online service. 36 was the chosen number because 123D Catch requires about 36 pictures. 30 of the pictures are taken at a near even level with the object and 6 are taken at a much higher angle, such as 30-45 degrees. The high angle shots mesh with the low angle shots in the app to give the object its 3D form. This formula of 36 pictures was successful in the app, but led to failure during initial attempts with the ReMake software. During initial effort, the mesh software failed to create a 3D object. Rather, a 3D object would appear to be a combination of the table the object was placed and the object itself.

After more in-depth research, the team began a new trial with the information learned[4]. Through these sources, it was learned that the use of our reflective wall plug-in iPhone charger was not the ideal subject for meshes created by the software. The software has trouble recognizing points where the light is being reflected consistently, which meant certain actions would have to be taken in order to mitigate the reflection. Washable chalk paint, available at most retail stores, was one of the methods that could be used to reduce glare (similar to a dulling spray used in Konica Minolta scans). The charger was also symmetrical and had little detail to differentiate which sides were which, so the software struggled to make a mesh because it was not sure how to form each side. A suggestion by the AutoDESK team led to the use of stickers with numbers written on them to spotlight the different geometry of the new object (a 3D Printed skull) being scanned for the software. The labels acted as a typical position dot would for a typical 3D scanner such as the Handy SCAN. After the use of the stickers, the team began to use these dots from a department 3D scanner to differentiate geometry. Even when not necessarily required, the dots improved the scans dramatically. A metal 3D printed historical figure was used with the positioning dots and required very little editing afterwards.

Editing proved to be a vital resource of the ReMake program[5]. The object for a test, in this case a previously 3D printed skull, was placed on a podium in the center of the office on a few pages of newspaper illustrated in Figure 1 and 2. Rather than 30 photos taken at eye level with the object, 40-50 were taken at this level and about 20 were taken from a higher angle. Care was taken to slow down the process of rapidly taking photos to allow the stabilization of the camera to take effect. After the shots of the object were taken, the photos were put into the cloud that ReMake uses in order to generate a model online. The model was placed into ReMake's queue and then processed over several minutes as shown in Figure 1. The first successful mesh, the previously 3D printed skull, was created by the program along with the newspaper background from the podium as shown in Figure 2. The team were able to successfully create several different meshes of new objects with little to no trouble afterwards. Editing of these objects was a challenging task at first, but once the team was comfortable with the software and the different tools at its disposal, it was able to 3D print pieces with very few deficiencies. Editing the skull and other objects first involved removing the extraneous material from the mesh, such as the newspaper. The newspaper demonstrated the capabilities of the software as the articles were still plenty readable (as seen in Figure 2) before they were removed. Like with many scanning technologies of a similar type, the software does not always fill every gap on the model. Most of the time, our gaps were near the bottom of the mesh. This is understandable because it is difficult to get the smart phone at the correct angle to hit the base in contact with the table surface. Fill holes feature was able to fix the small defects the team had. From the camera shots, the team would occasionally run into an area on the mesh that was more rigid than its parent model. Simply using the smooth tool and adjusting the brush size to small and making the brush strength weaker allowed the team to make the precision fixes to our model. The team did not make much use of the sculpt tool, but it has the ability to touch up small areas similar to the brush.

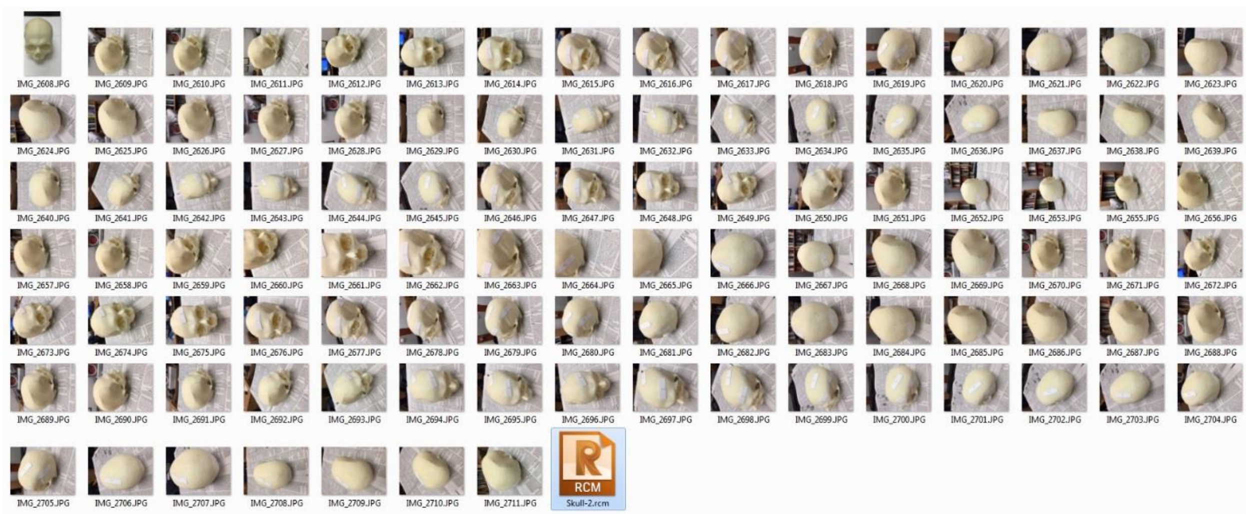

Figure 1. Multiple photos of the skulls taken by a smart phone being loaded to Remake

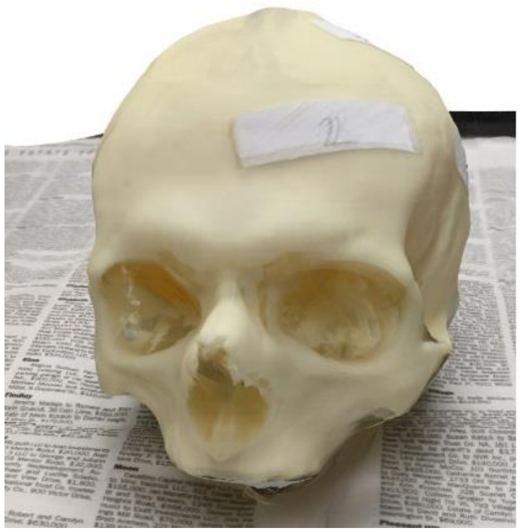

Figure 2. Original 3D model generated by ReMake

After working with static objects, the team wanted to test out how well the software handled a human subject. The human subject would be different for the software because of the inability of a human to remain perfectly still while a workable number of pictures are taken. Our subject, a faculty member's daughter, was to hold a dancing pose that we hoped could be used for a small figurine. While almost 200 images were taken, no combination of the images was able to generate a well-defined, whole body model. However, the software was able to generate a model from the shoulders up. The model was not perfect, but using the editing tools available on ReMake created a print-worthy piece. The slice and fill removed most of the imperfections from the bottom of the model, and left only the need to work on the head. The head was generated with a few minor holes, but these were removed quickly by the fill holes feature. The head was smoothed by the use of the customizable brush size and strength tools, which removed the assorted small bumps and edges the head contained. A broad brush size with lower strength proved to be the optimal set up for evening out the smoothness of the head. The person was the most difficult subject the team attempted to make a form of, and the ReMake software was able to handle most of the person. However, a large amount of editing was still required to prepare a bust for a better print.

Following results can be deduced from the experimentation:

- When taking pictures, it is important to have the camera as close to the object as possible.
- Monochromatic backgrounds for the photos did not work because the software had nothing to use as reference points. Newspaper worked very well.
- Time must be taken when taking the pictures to allow the focus of the camera to do its job. Blurry backgrounds are not ideal.
- Markers, dots, or any sort of label are a must when the object has symmetry of any kind. The team ran into a problem during our first attempt with the skull where no sort of

reference was detected by the software on the left side. The right side was 3D but the left lacked any depth and actually seemed as if it collapsed into the right side.

- As the experiments progressed, the team was able to take slightly less photos. The importance lies within the quality of the shots, not necessarily the number of shots.
- Seek 40% overlap as a minimum threshold value in each of the photos.
- When slicing the model, the team found the x-ray view to be especially helpful for precise slices.
- Larger holes were easier to patch by filling them with the flat option, rather than the smooth option, similar to flat vs polynomial fills in Geomagic.
- In overall, once the team learned how to take appropriate photos and use the editing tools, it found ReMake to be an extremely user friendly program that created quality meshes, even when using the standard instead of the ultra-mode.

Class Learning Experience

As the experimentation was carried out by the work-study student and instructor team, the Rapid Prototyping and Reverse Engineering class students were given an open-ended scan assignment using 123D Catch. A range of results were obtained, a couple of which are presented below in Figures 4 and 5. Knowing that 123D Catch does not have the edit features the students need, some groups used software programs like Mesh Lab or Meshmixer to improve the quality of their 3D Images as the one shown in Figure 5.

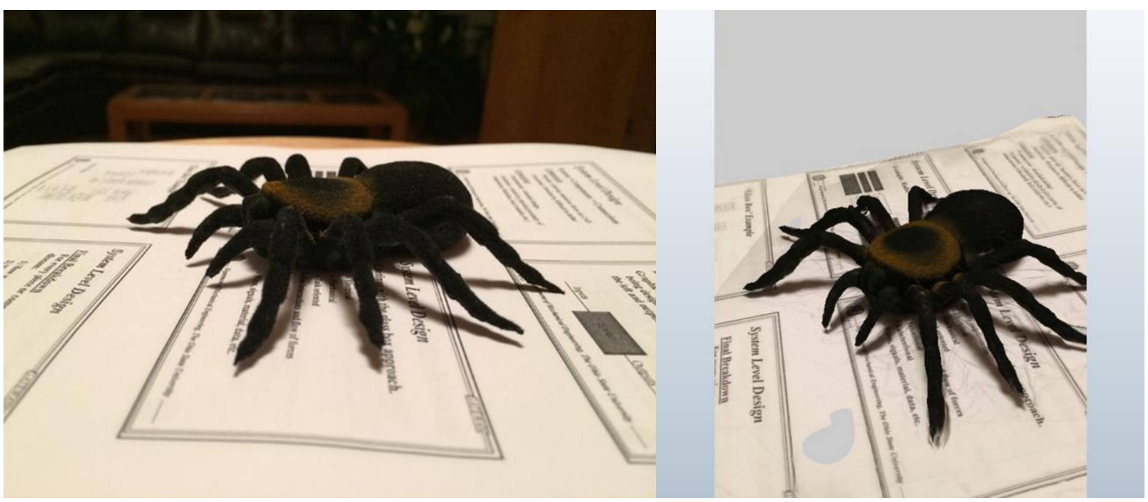

Figure 4. (a) A photo taken by a student's smart phone (b) 123D Catch model obtained by multiple photos

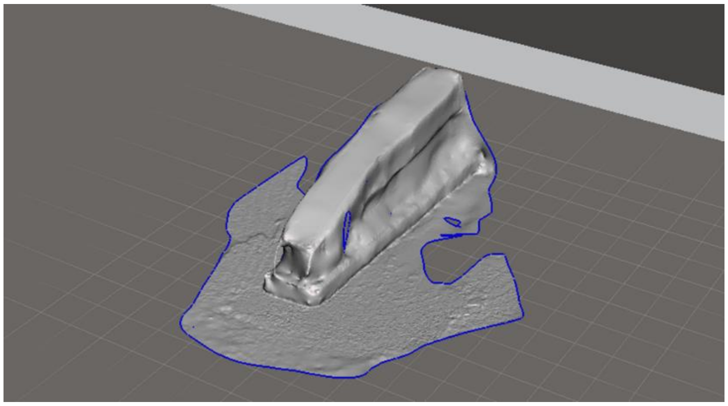

Figure 5. 123D Catch model obtained being edited in Meshmixer

Rapid Prototyping

As mentioned earlier, multiple low cost Rep-Rap (<$1K) and 3D Systems Cube machines ($3K+) are being utilized to help reduce the strain on the commercial industrial or benchtop printers available in the laboratories. In addition, some students are using the 3D printers available in the library or owning their own machine. Even though Cube machines do not deliver as good quality as Makerbots, they still help reduce the strain on the UPrint SE machine as shown in Figure 6 – a Nylon toy design printed with a Cubo Pro Duo machine. These machines also allowed the instructor to increase the range of materials from ABS and epoxy resins to Nylons and poly-lactic acid (PLA).

Figure 6. Toy project printed by a 3D Systems Cube Pro Duo

Conclusions

The purpose of this work was to grow the 3D scanning and printing resources available to large number of students. Students are now able to access larger number of low-cost hardware along with freeware software tools. The experimentation conducted with the smart phones and cloud-based scanning software will be used to improve the course materials for the next year's offering. In addition, the development team realized that AutoDESK offers other uses of the freeware software for measurements and analysis as well as CNC routing. These capabilities will be a focus of future work as the team develops the 3D scanning activities for the class. While the original feedback from the class included excitement, the lack of presence of editing tools in 123D Catch and no additional instruction limited student interest in this year's class. Following ABET student outcomes will be impacted by this effort based on the results of the work-study student efforts:

- (Outcome b) an ability to design and conduct experiments, as well as to analyze and interpret data. Similar experimentation will be added to the curriculum next year.
- (Outcome e) an ability to identify, formulate, and solve engineering problems. Student will be asked to solve lighting and geometric feature detail problems.
- (Outcome f) an understanding of professional and ethical responsibility. Since the ethics is a part of the course curriculum, a simple case study on the impact of 3D scanning over reverse engineering ethics will be included in the next offering.
- (Outcome i) a recognition of the need for, and an ability to engage in life-long learning. The materials prepared for the next year will also include activities relying on facilitation forcing students to locate and learn some of the components by themselves.
- (Outcome j) a knowledge of contemporary issues. Rapid prototyping and reverse engineering are one of the most exciting areas of today, and by learning the developments through the new low-cost and freeware tools, students will be current.
- (Outcome k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. Again, the tools utilized in this class will include some of the newest ones in their field.

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