Creating a 3D Model without CAD: Tools and Tips for Laser Scanning and Photogrammetric Techniques

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Abstract

Most engineering students have access to 3D CAD tools to create solid models used for communicating design intent, preparing FEA studies, and facilitating direct digital fabrication. However, some objects cannot be constructed using feature-based CAD. They may be more organic in nature, or might have complicated curves and surfaces that are difficult to generate in a feature-based program. In addition, point cloud data might be available that would require surfacing to adequately represent the part size and geometry. Perhaps the only data available is a series of carefully organized photographs of the object in situ.

This paper summarizes experiences in collecting and manipulating point cloud data for use in CAD, 3D printing, and digital measurement. A review of common laser scanning and photogrammetric tools will be presented, along with examples of student and faculty projects. Included in the software discussion are options ranging from open-source to freeware to commercial products.

Keywords

Laser, Scanning, Imaging, Photogrammetry, 3D

Introduction

The increasing proliferation of rapid prototyping devices has made the creation of direct digital manufactured components a common practice in the engineering design curriculum. Students quite easily master the basics of 3D modeling, allowing the generation of Standard Tessellation Language files (STL files) for 3D printing. The situation often arises when students need to reproduce something that was not or could not be easily modeled. Laser scanners have been shown to be effective tools for the undergraduate design and laboratory curriculum. [1,2] These scanners generate "point clouds" of data representing the outer surfaces of the scanned object.

Experienced students can generate useful 3D point data fairly easily using laser scanners of various types. This data can be converted to the STL format for printing very easily. Solid surfaced objects in formats such as STP or IGES can be created, but manipulating the data can be difficult and generation of a feature based model slow and tedious. Photogrammetric techniques show promise for generation of models, but the learning curve can be steeper and knowledge of good photographic technique is essential. New cloud based platforms such as 123D Catch[3] even allow the generation of point cloud data from digital photographs, using a phone app or a digital camera teamed up with a desktop client.[3]

The particular technique selected depends upon the final goal. If a feature-based model is the desired product, a fully equipped laser scanner with optional reverse engineering software might be the best choice. If the goal is to reproduce an object for 3D printing or to create a "dumb solid" such as a STP or IGES file, a cloud-based solution or a low-end scanner would be ideal. If a model is needed for measurement of a forensic scene, then camera photogrammetry might be ideal.

Basics of point cloud collection

When creating a digital model from 3D point data, the same core steps are utilized whether the method is a laser scanner or photo based software. The first step is to plan the project, making decisions about how the part will be held and supported and what regions might be obscured in a given orientation. Students often try to skip this step, but a good plan will save time and improve the overall quality of the model. The second step is to capture the scans or images of the object desired. Trimming of excess scan points might be required. The remaining individual point clouds must now be aligned, using object geometry or fiducial targets attached to the object. The last remaining step is to fuse the scans into a single unified mesh; this is often the most difficult step. The demands on the computer running the software are typically highest during the fusing operation. Most of these phases are performed by computer software and/or hardware associated with the product, although good operator judgment is always required.

Exporting these point clouds is where the value of the scanning process is realized. Most systems can easily export a triangle tessellated file (STL) for use with a 3D printer. An STL editor might be needed to fill holes for a "water-tight" model, but multiple online and free packages such as netfabb[4] can do this. The 3D printer might even provide software for this task.

Creating a feature-based CAD model from the point cloud is much more difficult. The student version of SolidWorks[5] contains the "Scan-to-3D" add-in that permits various scan formats to be brought into the software. Those point cloud files can be used to create a surfaced model, but this can be a very difficult task. The easiest approach might be to use the point cloud as a reference for the creation of new geometry, allowing the point cloud to serve as a guide to the geometry. This is the basic structure of the premium product in this category, Geomagic Design X (formally known as Rapidform)[6]. However, these products are not for the casual user since the learning curve is steep and the costs are high. Some academic programs have made successful use of them[7], but that has not been the experience with students in our institution.

So what are the low cost and easier options for creating files, based on point cloud data that can be read into a 3D CAD program such as SolidWorks and functions as a solid object? Perhaps that solid will only be a "dumb solid" that cannot be edited at the feature level, but it can be cut and additional material extruded to it. It can also be trimmed and added with mates to an assembly.

Two methods to generate a point cloud from a physical object are overviewed below, as well as tips and advice on how best to utilize equipment and software associated with these methods. The first method discussed is laser scanning via the NextEngine and the DAVID laser scanners. The second method is photo-based software such as Photomodeler and 123D Catch, an Autodesk product available in desktop as well as phone app platforms.

The basic challenge still remains on how to convert these point clouds to useful solid objects. The end of the paper contains a process that has been created to convert a WAVE FRONT file (OBJ) point cloud into a 3D CAD file, such as a SLDPRT for SolidWorks. The standard operating procedure (SOP) for converting OBJ files into SLDPRT files is provided in the final section of this paper entitled "SOP: From Point Cloud to Useable CAD file."

NextEngine Laser Scanner

The NextEngine laser scanner[8] is a portable desktop scanner that is surprisingly user friendly and has attractive academic pricing. A turntable is included which aids in the positioning of the object to be scanned, as shown in Figure 1 below. These scanners provide a wide range of automated scanning options, and work reasonably well to collect point clouds. The device has an onboard camera and a pair of line lasers which traverse the part slowly. As you can see in Figure 2, on the following page, the lines will distort as they encounter surfaces off the normal viewing plane. For instance, note the curve that is generated when the laser line moves over the hole. The software can compute the shape of the object based on the motions of the lines, since the angles and distances between the laser source and camera lens are known[9]. Since it is a red visible laser, it is important to scan the object in a dark environment, and to use the proper settings in the scanner software.

Two software options for the NextEngine are available, and have good academic pricing. The first is the CAD TOOLS option, which allows the saving of the scan files as STEP and IGES files that can easily be imported into 3D CAD packages. This option is extremely important for those wanting to import those scan to CAD, but unfortunately the NextEngine software is locked to only open point clouds from its scanner. It is not a universal tool for point cloud operations. The second option is a version of the Geomagic Design X software mentioned above, tailored to specifically to the NextEngine scanner. It has all the strengths and weaknesses, coupled with the steep learning curve, but once again it is locked to only NextEngine scans. Our experiences have been mixed with this option and we would not purchase it again.

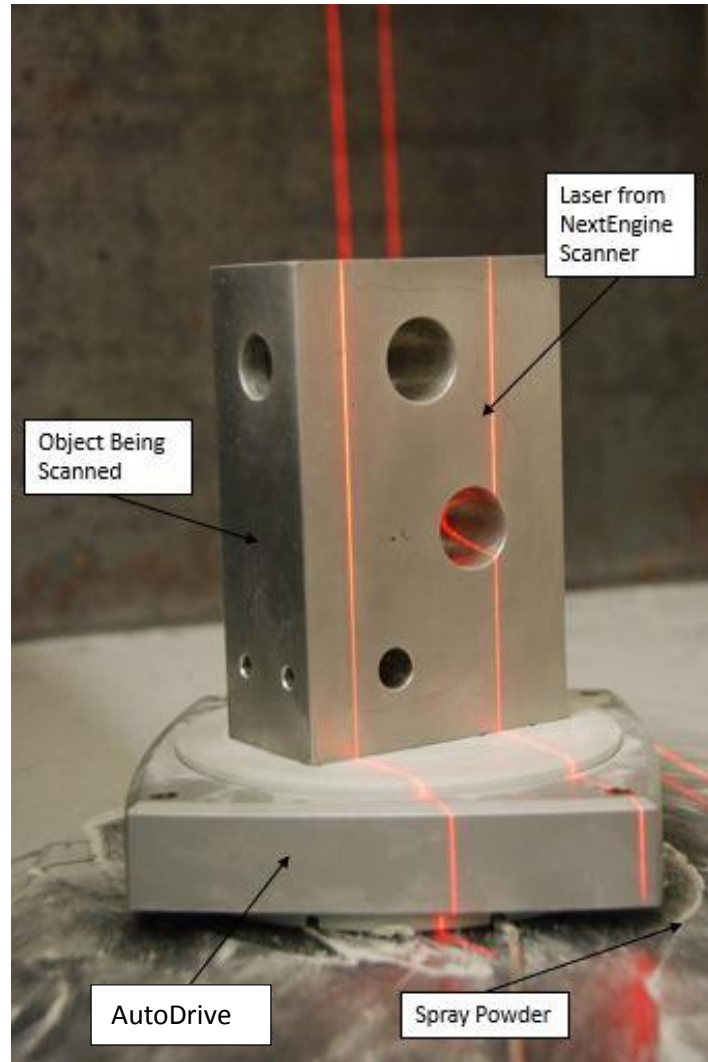Figure 1: The NextEngine Desk top laser scanner1.

Figure 2: An example of the NextEngine scanning an object. The photo shows four separate lasers being used to generate a point cloud model of the part shown. The white residue on the counter top is spray powder used to alter the surface reflectivity of the part.

NextEngine Scanner Tips

Before using the NextEngine laser scanner to create 3D point data of a physical object 6 steps should be followed. The first step is to plan the scan. The color and transparency of the object effects the quality of the 3D point data captured during the scanning process because the scanner analyses the reflected laser light. The scanner measures the time and amount of light that is reflected back to it in order to generate a point cloud or mesh of the object. Therefore the reflectivity of the surface is important. If the physical object's surface is dark, shiny or clear the laser scanner will not be able to create an accurate 3D point cloud of the data that is captured during the scanning process. Lotrimin powder spray can be used to temporarily alter the surface of the object being scanned. Varies types of powders and powder sprays were tested and Lotrimin (miconazole nitrate) powder spray was found to eliminate reflections and hot spots in

the image from the laser. In figure two the white residue seen on the counter top is powder used while generating a point cloud. If the object can be permanently altered then white paint can also be used to change the surface of the object.

In the event that the object is complicated or self-excluding then multiple scans will have to be combined to fully capture its geometry. To assist during manually aligning multiple scans fiducial marks can be used. Fiducial marks are symbols, letters, or numbers that can be drawn on the surface of the object or the surrounding environment. Those drawings will give an adequate amount of reference points to align your scans together. Multiple scans can be aligned without the use of drawn on reference points, but depending on the complexity and the size of scans it can be difficult to identify the same points on both scans. If the surface of the object cannot be altered then draw letters, numbers or symbols on sheets of paper or a pedestal and place your object onto it. Make sure that the pedestal or paper with the drawings is included in your scan window. The flow valve in figure three has be placed onto several pieces of paper with letters, numbers and symbols written on them because the flow valve could not be altered.

The next step is to select what settings to use on the scanner software. There are five settings to take into consideration: positioning, divisions, points/in^2, target, and range. Depending on the settings and the object being scanned a device called AutoDrive can be used. Autodrive will be discussed in detail further in the paragraph. The positioning has three options: Single, Bracket, and 360. Single should be used when scanning only one face of the object. If the object being scanned weighs under 20 pounds, then the AutoDrive turntable can be used to automate the scanning process. The AutoDrive allows you to use the 360 setting or the Bracket setting. When using the Bracket setting the scanner and the AutoDrive work together to automatically scan two sections of an object. While using the 360 scanning option, the NextEngine Scanner and AutoDrive work in unison to complete a 360 degree scan of the object. When using AutoDrive turntable it is a good idea to place the object being scanned onto a square or rectangular pedestal. The square or rectangular pedestal gives the scanner a defined edge to reference while scanning the object, and for aligning the 3D point data. If the object has no defined edges then the software has the habit of filling in, curling, or bowing the point data it collects into areas where no data should be. If a large object, such as a flow valve, is going to be scanned the NextEngine can be attach to a camera mount, as seen in figure three. When the AutoDrive turn table is not being used there is no choice but to use the single setting in the position option.

The next setting is Divisions. This setting controls how many total scans are taken while using the position options Bracket and 360. The options for this setting range from 4 to 16. When using the 360 position option the number of scans (S_t) the NextEngine will take is determined by the total degree of rotation (360°) of the AutoDrive divided by the number of divisions (n),

$$S_T = \frac{360°}{n}. \qquad (1)$$

While using the Bracket position option the number of divisions will determine the total number of scans the NextEngine will take to the left and right of the center line, as shown in figure four. Most scans will not require the maximum number of divisions to create a detailed scan. The majority of scans will only require at most 12.
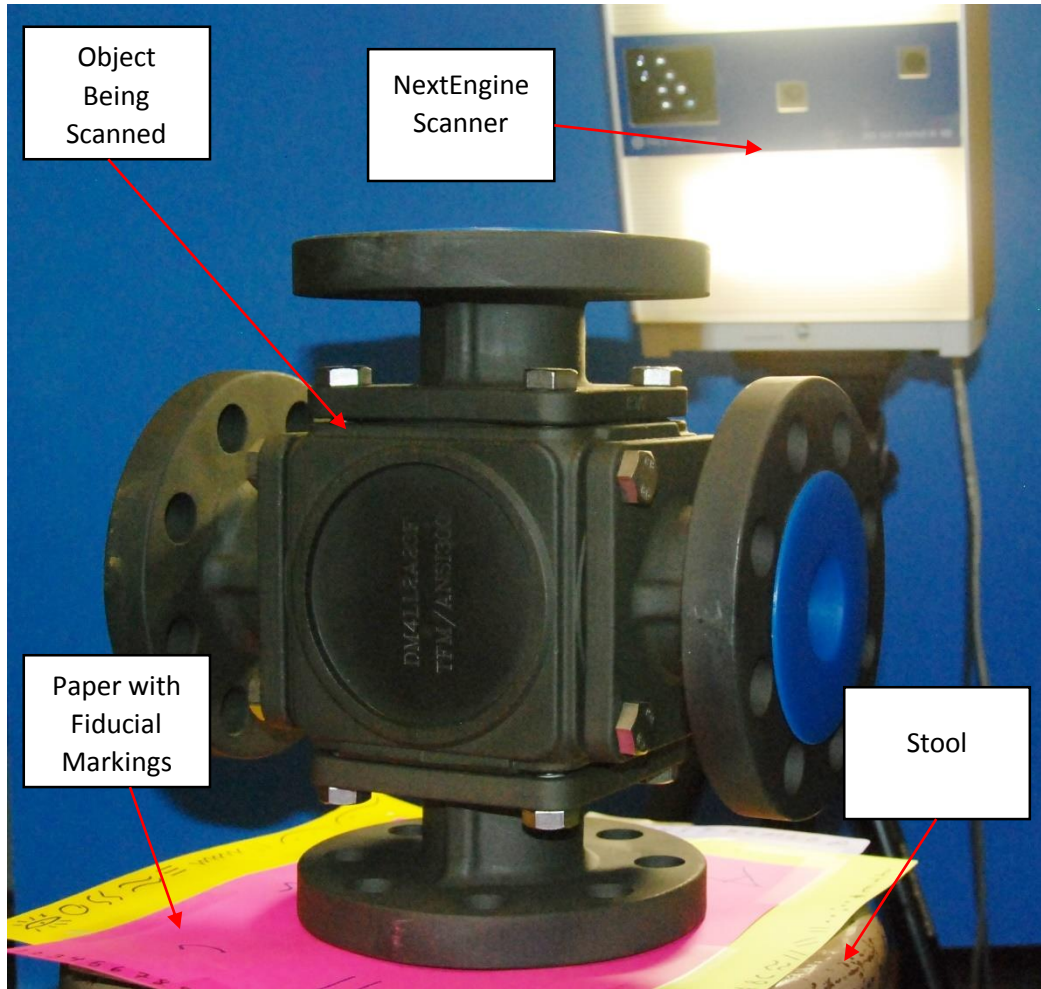
Figure 4: An example of a large object being scanned by the NextEngine Scanner. A flow valve that has been placed onto a stool to allow it to be turned in a circle. The valve has also been placed onto several pieces of paper with symbols letters, and numbers written on them to assist during the alignment process.

The next setting controls the point density of the cloud that is created from the scan of the object, Points/in^2. The settings range from 80{Points/in^2} to 160,000{Points/in^2} depending on the range option that is discussed later in this section. Most scans will not require this setting to be set to max in order to get a fully detailed scan. The governing factors when deciding what setting have value to use is depended upon the amount of time available and the amount of memory available on the computer. After deciding the density of the points in your mesh skeleton, the color type of the object you are scanning needs to be selected. In the setting called Target three options are given: dark, light, and natural.

The last setting to change is in the Range option. There are three options to select from: macro, wide, and extended. Macro is used when the object being scanned is small, and can be fully seen in the preview window from 6.5 to 8 inches away from the scanner. Wide is to be used when the object being scanned is medium sized and can be viewed from the preview window at a distance ranging from 17 to 20 inches. The last option is extended, this option is to be used when the object is large. For example, if the object being scanned is an industrial flow valve set the size/distance setting to extended, and measure the distance from the flow valve to the scanner.

When using the extended setting it is best to have the object 17 to 25 inches away from the scanner with the maximum distance of 30 inches. If possible place the large object on a turn table or stool, so that it can be rotated. If rotating the object is not advantageous then the NextEngine scanner can be moved around the object to complete the scan. The flow valve in figure four has been placed on a stool, and the scanner has been attached to a camera mount.
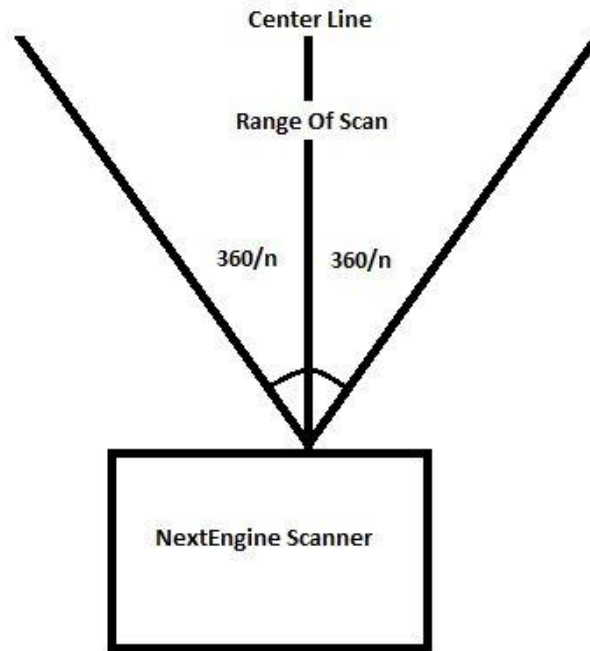

Figure 3: This figure shows how to determine the number of scans the NextEngine will take while using the position setting Bracket, and varies Position values.

DAVID Laser Scanner

The DAVID laser scanner[10] is a German product available at various US online companies. Functioning very similar to the NextEngine scanner, it is completely manual in operation. A hand-held line laser is used to create the scanning reference, while a PC controlled web cam records the scan image. The alignment of the scans is facilitated by the use of calibration panels, as seen in Figure four. These panels are sized in proportion to the object being scanned, and provide fiducial targets for the software to locate the scans. The cost of the system is about 25% of the NextEngine, and serves quite well for reproduction of smaller items that might be 3D printed. It does not have any surfacing capabilities in the software, and the creation of STP and IGES files will require the same process included at the end of this paper. We have had some luck with the system, but we would not recommend it for any large volume use. It serves very well as an experimental platform for instruction since it is manual, but it is like comparing a manual lathe to a CNC machine with respect to productivity.
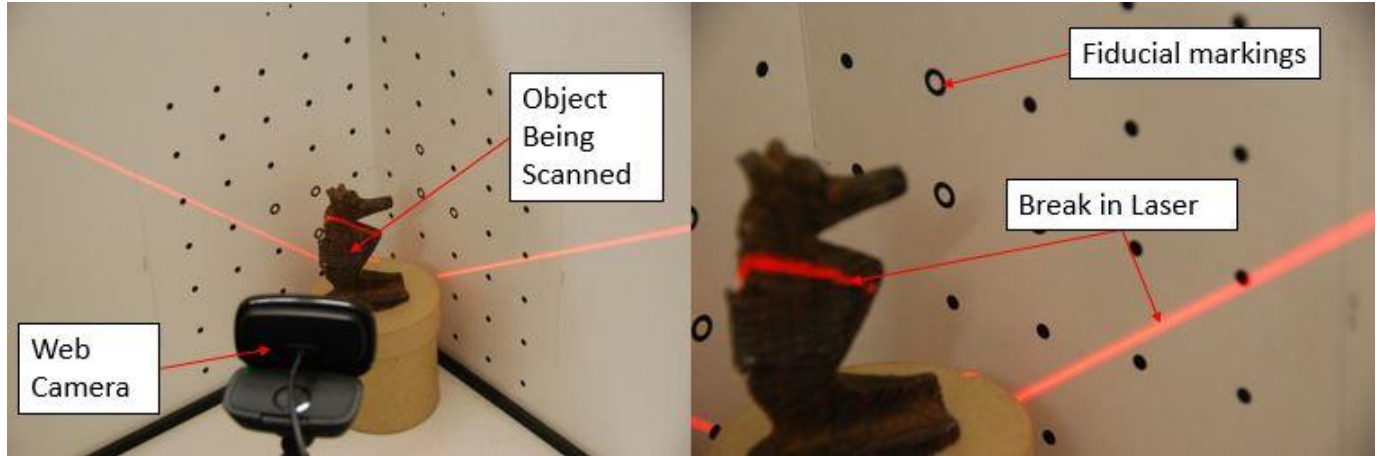
FIGURE 5: In the above two photos the object shown on the pedestal is being scanned by the David Scanner. The fiducial targets shown on the backdrop is used by the camera to create a 3D model of the object being scanned.

Photomodeler

Not all point clouds need to be generated from laser scanning. The next two packages build the point cloud up from photographs. The first is PhotoModeler[11] from Eos Systems, a full scale photogrammetric[12] package. Widely used in macro scale work, PhotoModeler allows for the calibration of a camera to the software so that photos taken of objects can be aligned and attached. The resulting models can be measured very accurately, even along planes where no photos were taken. In addition, IGES files can be created fairly quickly from these models, but as with many of these high level tools, the learning curve is steep, the cost is high, and the need for good photography is crucial. The PhotoModeler package is an excellent choice for architectural work, accident and crime scene reconstruction, and aerial photography. However, it's utility is not ideally suited to the typical undergraduate design project, we are using it primarily with aerial photographs taken by quadcopter.

123D Catch

123D Catch[3] from AutoDesk is a free program that is so easy to use it almost requires no instructions. 123D Catch allows for 50 to 70 photos to be uploaded to their server. After being uploaded, the photos are arranged together to create a 3D model. The software uses pattern recognition of reference geometry found in the foreground and background of each photo to create a 3D mesh skeleton. If the geometry, composition, or the exposure of any of the photos change it might cause the software to misalign the elements of the photos while creating the mesh skeleton. If the software is unable to align or has misaligned, the user can manually pin and unpin photos from the alignment tree. Even with this limitations 123D Catch is perfect for use in an academic environment due to no cost, and ease of use.

123D Catch Tips

Before using 123D catch to create a mesh skeleton of a physical object, a series of photos must be captured. The quality, and order of the photos are important. Before capturing the photos the following three steps should be followed. The first step involves planning, during the second step a series of photos of the object of interest are taken, the last step involves using the software to create a point cloud, and then retaking photos to correct any miss spots or gaps in the point cloud.

The first step is to plan the photo shoot. The order and manner in which you take the photos are important. 123D catch requires 50 to 70 photos to create a mesh skeleton, so every aspect of the object needs to be shown in the photos. The lighting, composition, placement of the object of interest, and exposure of each photo needs to remain constant. For example, if there is a light source creating shadows in 25 of the photos, and then that light source is turned off or changed in 25 photos, 123D catch will not be able to auto combine the 50 photos into a mesh skeleton because the reference geometry was not constant. The object of interest should also be photographed in an environment that is relevantly private. If people or other objects are moving in and out of the photos the software will not be able to auto align. If it is not possible to take the photos in a relevantly private environment or in a location where the light source is constant then the user will need to manually align the photos in order to combine them into a 3D model. In addition, fiducial objects can be placed into the environment to increase the amount of reference geometry and to assist in manually combining the photos. Fiducial objects with a known distance can also be used to ensure the 3D model is to scale, and to be use a reference when taking digital measurements.

The second step is to take a series of photos in a helical pattern while keeping the object of interest in the center of each shot. This is the easiest way to insure that every aspect of the object is included in the photos. The maximum number of photos that can be used in 123D Catch is 70, so it is important to only take 60 to 65 photos during this step. The 5 to 10 photos leftover will be used in step three if the 3D model is not complete.

The third step is to create a new project in 123D Catch, upload the photos taken in the second step, and then wait for the software/server to create and download the 3D point cloud of the object you photographed. After the 3D point cloud has downloaded, look at the model, and examine it for any holes or empty spots. Take 5 to 10 photos, depending on the number of photos left over from step two, of the object, and this time focus on the areas that were missing in the 3D model. After photographing the object of interest, repeat step three, but upload the photos from step two, and the new photos taken. Figure six shows an example of an object that was photographed and then turned into a 3D model by 123D catch.

Figure 6: An example of an object that was turned into a 3D point cloud by using 123D Catch. The object on the let is the object of interest, a gargoyle and the object on the right is the 3D model created by 123D Catch. The build -in camera of an IPad was used to collect the photos for use in 123D Catch.

SOP: Point Cloud to Useable CAD File

By exploring the range and limitations of a wide variety of computer software ranging from 3D imaging programs, to format converters, to CAD, and even to 3D art programs, a systematic approach has been created to convert an Objective (OBJ) file into a workable CAD file. With the use of a digital camera, and the free software 123D Catch, from Autodesk, 70 photos of a gargoyle statue were turned into an OBJ file. That OBJ file was then taken and turned into a "dumb solid" or "imported surface" in SolidWorks. The process listed below will work for any OBJ file.

The subsequent procedure makes use of the following software's Auto Converter[13], MeshMixer[14], Rhinoceros[5], and Solid Works[16]. Auto Converter, from AUTOMAPKI, is a software that allows for multiple 3D files types to be imported and then exported as a different

format. MeshMixer is a software that allows for the creation of 3D models from scratch, and the editing of imported 3D files. Rhinoceros (Rhino) is a 3D modeler software that is fast and easy to use. Rhino allows for different types of 3D files to be opened and for the mesh/point cloud of these files to be edited. In addition, it allows for files to be exported as different types. However, Rhino cannot export polygon meshes as an IGES file, and that is why Auto Converter is necessary. The last software used in this procedure is SolidWorks 2014[16]. SolidWorks is a prototyping software that allows for the design, development, testing, and verification of a 3D model or assembly of multiple models.

Step 1. Export the 3D model from 123D-Catch as a WAVE FRONT FILE (OBJ).

Step 2. Open Auto Converter (from AUTOMAPKI), and examine the model. If the model is open, the end result will be an imported surface in SolidWorks, not a dumb solid. If the model is open and the outcome is intended to be a dumb solid, continue to step three. If the model is open and the intended outcome is an imported surface, skip step three.

Step 3. Open the OBJ in MeshMixer, and use the make a solid tool. Save and export as an OBJ.

Step 4. Start Auto Converter, and open the OBJ file. Fill holes, unify normal, and then save the OBJ as an IGES file. If Auto Converter takes over thirty minutes to convert the OBJ, go directly to step seven.

Step 5. Open the IGES FILE from step four in Rhinoceros 5, and export your file as a new IGES FILE. When the IGES file from step four is first opened in Rhinoceros it may take several minutes to open, depending on the size of the IGES FILE. When the file is exported as an IGES, an option menu will appear and ask the user what specific IGES file type they would like to create select SolidWorks solid or SolidWorks surface. Save the file. If Rhinoceros takes over thirty minutes to convert the IGES FILE, go directly to step seven. Rhinoceros has several different options for the specific IGES file type ranging from Inventor 5, Pro/E, to Surfacer however only the SolidWorks option has been tested for this paper.

Step 6. Open SolidWorks 2014, and then open the IGES file from step five. After the file has opened in SolidWorks save it as an SLDPRT. If SolidWorks takes over thirty minutes to open the IGES FILE, go directly to step seven. Figure 7 shows an IGES file that was created in Rhinoceros and then saved in SolidWorks as an SLDPRT.
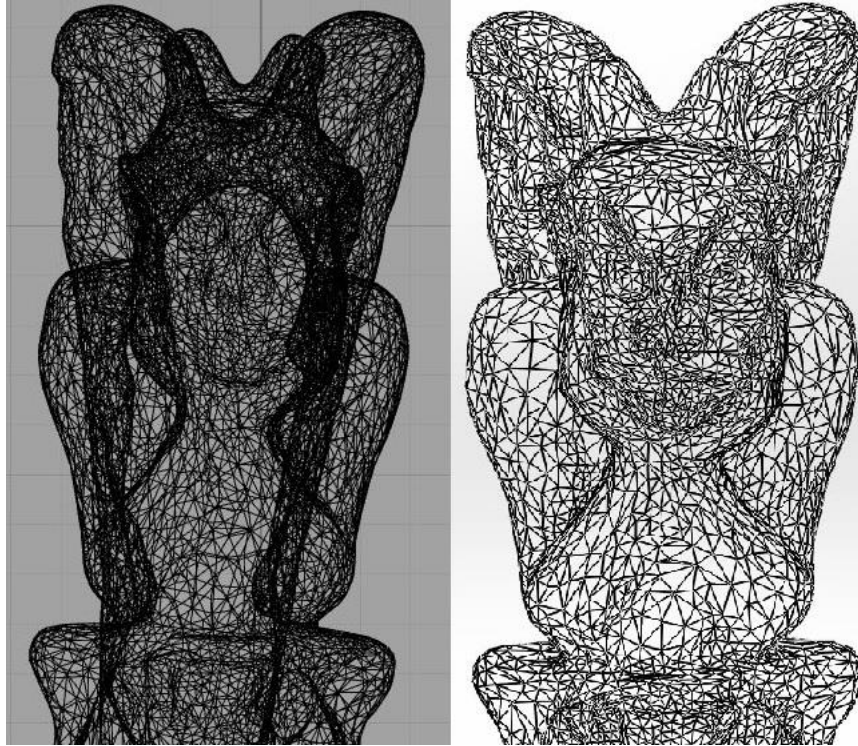
Figure 7: The object on the left is an IGES file that was created using Rhinoceros, and the object on the right is the dumb solid created by SolidWorks and then saved as an SLDPRT.

Step 7. This step should be followed if the Auto Converter, Rhinoceros, or SolidWorks takes over thirty minutes to complete their given tasks. Open the OBJ in Rhinoceros and reduce the mesh by 20%-30%, depending on its density. Repeat process starting with step two.

NOTE: If the mesh is reduced below a current density SolidWorks will only open the IGES file as an imported surface, not a solid. With an imported surface you will be able to select a point, draw, create a plane, and build around the surface, but you cannot cut or edit the surface.

Future Applications and Conclusions

By using the standard operating procedure for converting point cloud data into a useable CAD file OBJ files have been converted into SLDPART files and used for design purposes such as creating molds, and reverse engineering. The software 123D Catch, and the standard operating procedure also show possible applications for forensics analysis. Still frames taken from videos could also be used to create a 3D model by using photogrammetry software, such as 123D Catch. Figure 8 shows a photo of a mold created in SolidWorks by using the SOP given in this paper. Seventy photos of the second author of this paper was taken by his daughter and using 123D Catch those photos were turned into a 3D model. The SOP was then used to turn that 3D model

into a SLDPART file where it was then turned into a mold, figure 8. This figure shows that a possible application of the SOP given in this paper is the creation of molds for use in manufacturing.
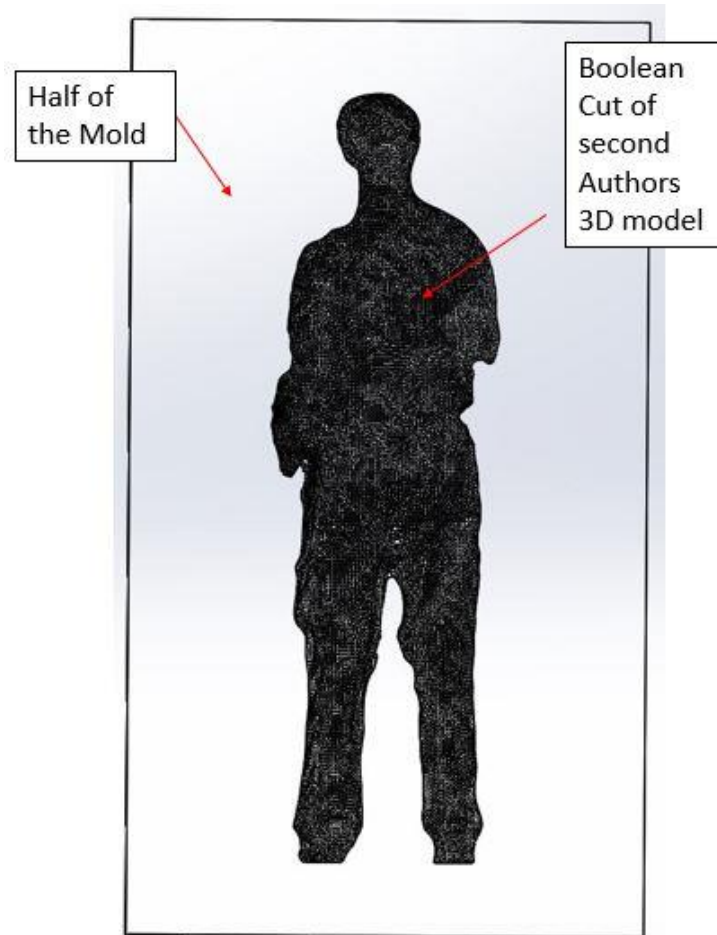

Figure 8: A mold of the second author of the paper

Another possible application of the SOP and the photogrammetry techniques given in this paper is in the field of forensic analysis. A shoe print was made in a box of sand and 70 photos were taken of that imprint. Using 123D Catch those photos were turned into a 3D model. By viewing the 3D model in Auto Converter and then rotating it and examining the bottom side, key features of the shoe can be identified. These features were then used to identify the type and brand of shoe used to create the imprint. Figure 9 compares the sole of the shoe used to create the imprint and the bottom side of the 3D model created from that imprint. A possible future application would be to use the digital measurement feature of 123D Catch to determine the weight of the person who left the imprints. Using this feature the height and stride of the given person could be obtained.
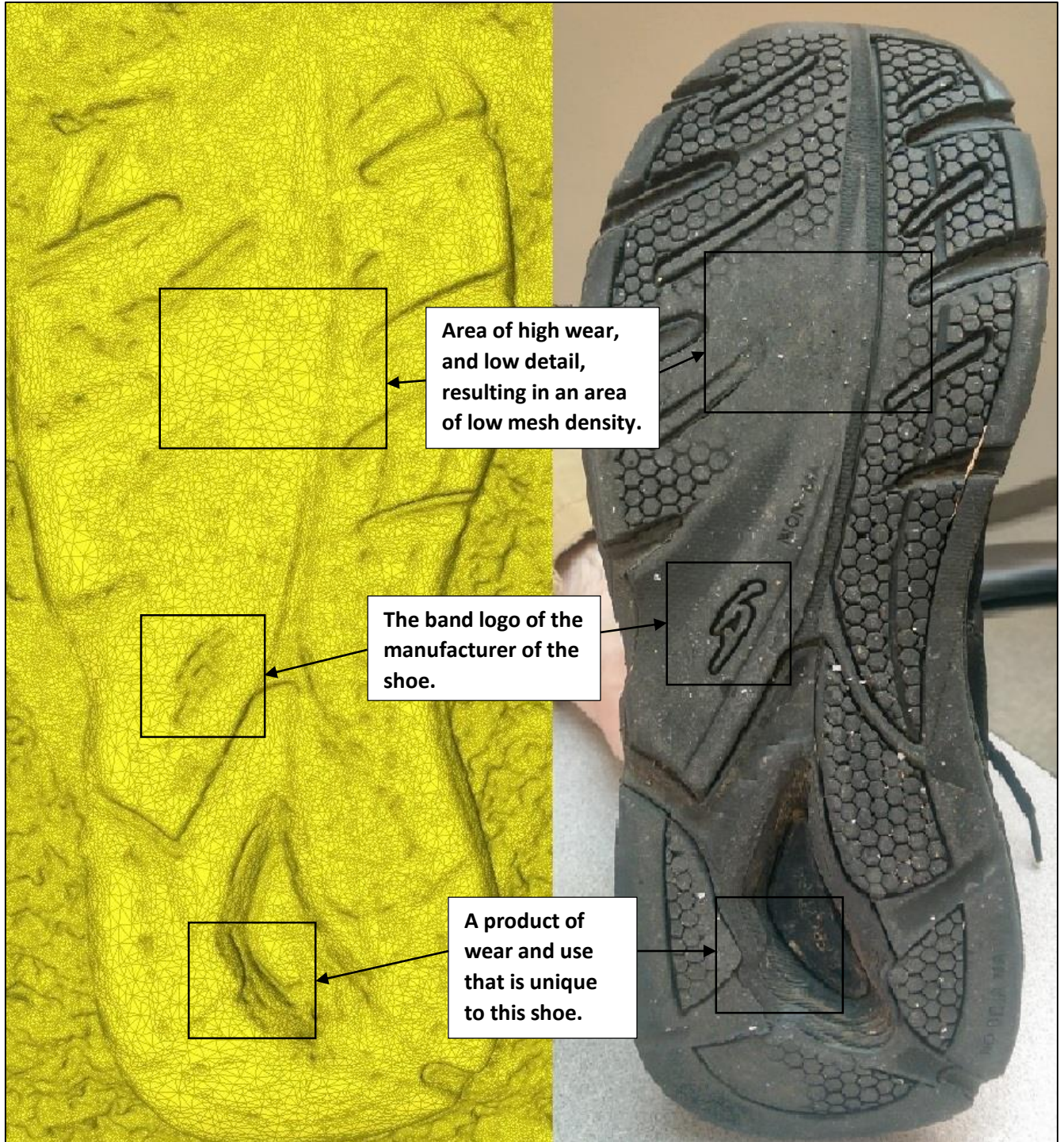
Area of high wear, and low detail, resulting in an area of low mesh density.

The band logo of the manufacturer of the shoe.

A product of wear and use that is unique to this shoe.

Figure 9: On the left is the bottom of the 3D model of the shoe print. The right shows the bottom of the shoe used to create the shoe imprint.

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