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Teaching 3D Scanning in an Effort to Teach Non-Industrial Use of Preservation of Art and Historical Artifacts

Dr. Arif Sirinterlikci Ph.D., CMfgE, CPEM, Robert Morris University

Dr. Arif Sirinterlikci, Ph.D., CMfgE, CPEM is a University Professor of Industrial and Manufacturing Engineering in the School of Engineering and Science (SES) at Robert Morris University (RMU). He holds BS/MS degrees (both in Mechanical Engineering) from Istanbul Technical University in Turkey, and his Ph.D. is in Industrial and Systems Engineering from the Ohio State University. He was involved in the ASEE Organization in the years between 2003 to 2011 as a Manufacturing Division Officer, also serving as the division's Chair 2010 -2011. He is also a member of Mechanical and Industrial Engineering Divisions along with the College and Industry Partnership (CIPD) Division. He is a co-author of the book titled, A Comprehensive Approach to Digital Manufacturing, which was originally published in April 2023.

Kristopher Connelly, Robert Morris University
Ryan Szekely, Robert Morris University

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Abstract

This paper is centered around teaching engineering students non-industrial uses of 3D scanning, especially preservation of art and historical artifacts. The lead author has been employing 3D scanning for non-industrial uses since engineering students may work for entities like museums, research societies, law enforcement, or orthotics and prosthetics offices after requiring this type skill and knowledge associated with it. Thus, even though it is not common in engineering education, the author feels that there is a place for this type of effort, since it may also allow graduates to work for industrial companies regularly employing 3D scanning. The lead author also values critical importance of preservation of cultural and scientific knowledge as much as unearthing or understanding them. This paper encompasses a look at the existing literature, also including work done in ship wrecks or anthropology areas, history of 2D and 3D scanning, their impact in digitizing efforts of various art forms, and physically replicating them with the help of new technologies like 3D printing. After setting the fundamentals and current state of artifact preservation, this paper focuses on 3D scanner use cases in preserving artifacts like paintings and statues, and replicating those artifacts by employing methods like 3D printing and room temperature vulcanization (RTV) molding. Student works completed outside class activities are included within the scope of this paper as well as its relation to student learning and ABET requirements. The paper is concluded with continued efforts focusing on possible future work.

Introduction

Utilization of 3D scanning in engineering education is becoming common [1], [2] with the digitalization of reverse engineering practices as a part of companies' digital transformation efforts, and some applications like custom human product development areas such as orthotics and prosthetics are already employing 3D scanning in full extent [3]. This paper focuses on teaching engineering students non-industrial uses of 3D scanning, especially preservation of art and historical artifacts.

Recent decades witnessed development of 2D flat bed scanners allowing us to digitize historical documents, books, and even paintings, making these works available to the masses. But as these devices became common in our schools, offices, and homes, 3D scanners were being developed in parallel. As a matter of fact, 3D scanners were invented in the 1960s when researchers began experimenting with lasers to measure distances and create 3D images based on their measurements. The first 3D scanners were bulky, expensive, and not very accurate. Over time, improvements in technology and computing led to more compact, accurate, and portable scanners. In 1998, Cyrax Technologies created the Cyrax, the first portable laser scanner [4]. Present day industrial 3D scanning technology can be categorized as follows [5]:

- 2D Digital Scanners and the Photogrammetry based-on 2D still pictures
- 3D Scanning Technology and Processes
    - Measuring Arms, Portable Coordinate Measurement Machines (CMMs)

- Scanners with Optical Tracking Devices
- Structured Light Scanners
- Portable Scanners
- Laser Scanning Process

These scanners use a variety of methods including, still pictures as in the case of photogrammetry, or a laser source and time of flight principles measuring time elapsed during return of the energy emitted by a LIDAR (Light Detection and Ranging) device, or visible white or infrared structured-light patterns to detect the deformation in an object as they are reflected on a surface of the object. Even though these methods mainly serve the industrial space, they have been used in scanning many historical [6] and anthropological artifacts including shipwrecks or dinosaur bones [7], even remains of crime victims to identify them.

Conservation and restoration of historical artifacts including art are as critical as unearthing or understanding them. Many institutions rely on manual labor and employ qualified people in their preservation efforts. The process of replicating artifacts is also not new, but it has also mainly relied on human talent. With the help of new 3D scanners, we are not only to be able to make digital copies (twins) of these physical artifacts and store the information forever including how they were made, but also, we can make physical replicas of them by employing 3D printing. Paintings are some of the most needed artifacts to preserve and are in 3D nature.

The lead author decided to add 3D scanning/printing of paintings to his course content (ENGR 4801 Rapid Prototyping and Reverse Engineering) to enrich the corresponding areas beyond 3D scanning and replication of obvious physical objects like toys or other everyday items. For that effort, a review of digitizing paintings was conducted [8]:

- Raking Light Photography (RLP): A technique that uses a single light source to illuminate the painting from almost parallel to it, creating shadows that bring out the painting's texture and surface topography. It gives detailed information including painting techniques, document losses and retouching, and reveal a painting's surface texture. Figure 1. is a good example where the investigator studies the topographical variations of the surface, visualizing cracks and other unevenness of the surfaces.

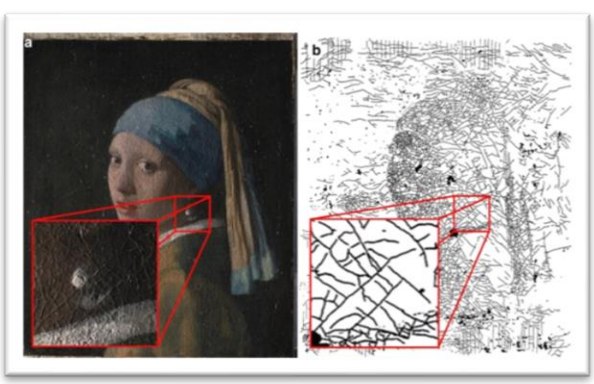

Figure 1. RLP studies painting and its cracking patterns, documented by manually tracing the cracks onto a transparent polyester film [8]

- Optical Coherence Tomography (a.k.a. Multiscale Optical Coherence Tomography, MS-OCT) [8]: An imaging technique that uses infrared light waves to create 3D images of structures inside tissues and organs as well as paintings. In paintings, it can visualize large-scale structures, such as brushstrokes, in underlying layers. It can also be employed to identify areas of damage, locate painting restorations, and highlight regions of interest of the paintings. Figure 2 below shows the study of the same painting from Figure 1 with MS-OCT.

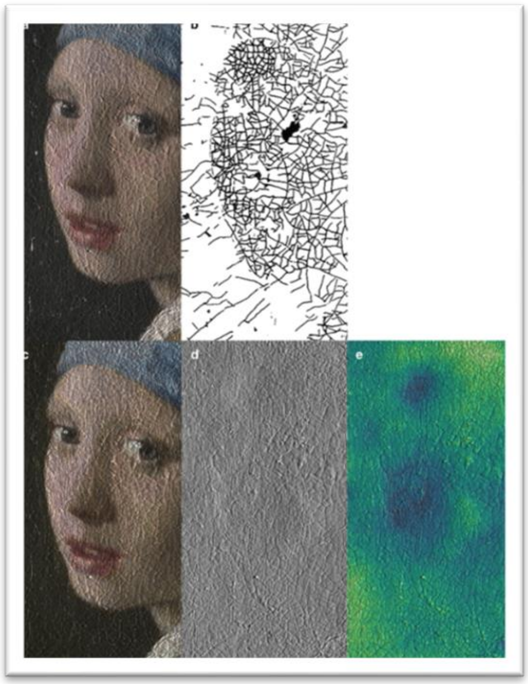

Figure 2. MS-OCT scan results and determined topology, brush patterns, and crack network [8]

Another advantage of MS-OCT is that it can be used to study paintings under different viewing angles, lighting conditions, and zoom levels. It can be also employed to see how the glaze layer in a painting creates a strong contrast between the figure and the background [9].

Case Studies

This section of this paper focuses on 3D scanner use cases in preserving artifacts like statues and paintings along with replicating these artifacts by 3D printing and/or Room Temperature Vulcanization (RTV). The work was originally carried out at Robert Morris University, outside the courses including ENGR 4801 Rapid Prototyping and Reverse Engineering as an extra-curricular activity, over a large span of years.

Bust Case Study

The subject of the first case is a U.S. Revolutionary War Hero – Robert Morris, the financier of the U.S. Revolutionary War. A plaster pattern used in making his statues was found in a storage room and given to Carnegie Museum of Art for restoration. The museum decided to document its state, by working with the lead author. The author was given the task of 3D scanning the most of important part (the top part – Figure 3) of the pattern which was later converted to a bust. The restored pattern, however, was not scanned. The following parts of this section presents the work involved in the project.

Figure 3. Robert Morris bust before its restoration

The project team included the lead author, a graduate assistant, and the laboratory engineer. A Konica Minolta Vivid 910 scanner (Figure 4a), a laser scanner, was used for the digitization process. The camera had the ability to capture large free-form objects with a dimensional accuracy of 0.127 mm. Because of the geometric complexity of the bust, special attention had to be paid to cavities and shiny surfaces. Since the scanner did not have the flexibility to reach hard-to-access details, the scanning process became more tedious than originally expected.

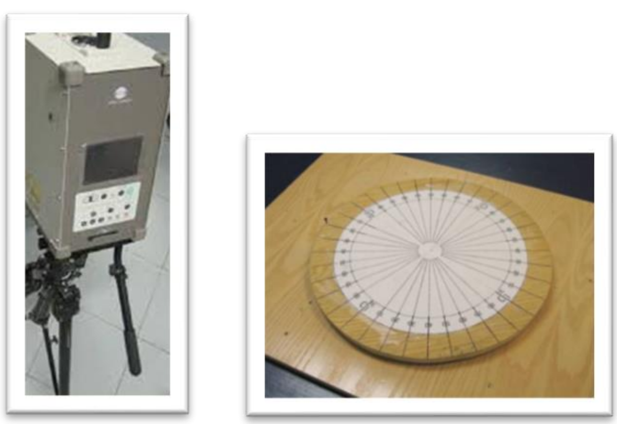

Figure 4. a) Konica Minolta scanner b) Manual turntable built for the project

The main difficulty encountered during the scanning process was the special care requirement in handling a historical artifact with a value of more than $100,000. The pattern would fit in a 914.40 mm × 914.40 mm × 914.40 mm work envelope and weighed approximately 27.22 kg.

The camera utilized is a photogrammetry tool taking still-pictures, and it requires an automated turntable for 360-degree capture of the objects. Such a large object with a vulnerable structure due to its fragile, aged body required that a special scanning platform be fabricated due to the small footprint of the original turntable, a Parker Automation 200 RT Series motor-driven rotary table with a diameter of 203.20 mm and a maximum load capacity of approximately 68 kg. Thus, a large manual turntable was made from wood, shown in Figure 4b. Actual turntable was left connected to the software and camera, and as each intermittent motion step occurred, the team members moved the large turntable manually. The camera took a picture of the object thinking that it was placed on its original turntable. The project team calibrated the new turntable as if it was the one connected to the PC with the Geomagic Studio software and accomplished each shot by matching the angle of rotation at the software tool and the manually driven table. Various rotation angles were tested. After a brief study, a rotation interval of 30º was selected as the stepping angle for the consecutive scans. As the Geomagic Studio software was instructed to rotate the original rotary table 30º for the next scan, the team manually moved the second table with the actual piece 30º. The captured data were processed within the Geomagic Studio reverse engineering software. 122 scans were done and their results merged automatically to eliminate redundant data. the resulting file was approximately 2 GB.

The 3D scanning process involves generation of point cloud, polygon (mesh) (Figure 5b), and shape phases (Figure 5c). At the shape phase, a watertight STL was obtained. Since the file size was rather large, the team decided lower the number of polygons and regenerated the STL file. This reduced the file size to 140 MB without sacrificing much of the critical data.

Figure 5. a) The bust after its restoration b) Polygon file c) Resulting STL

The STL file was later used to create 3D physical replicas of the original piece. Replicas were produced by using three machines: Stratasys Dimension Elite FDM machine, ExOne/Prometal R2 machine, and 3D Systems Viper SLA machine (Figure 6a, b, and c.). Prometal print became a master pattern for making physical replicas of the bust via indirect rapid tooling (Figure 7), RTV molding was employed to make inexpensive replicas of the bust, which find themselves interesting uses as Christmas ornaments, SAE Baja car signal lights, and trophies for the university's Science Bowl outreach event. Moldmax 40, a tin-cured silicone rubber, and Smoothcast 320 polyurethane material was selected for the original casting effort.

Figure 6 a) FDM- b) Prometal- c) SLA-printed replicas

Figure 7. RTV mold halves and resulting polyurethane replica

3D Scanning Paintings

A 70- to 80-year-old acrylic-based painting was selected for this project (Figure 8). The team for the projected consisted of two undergraduate students and the lead author as their supervisor. Team was supplied a Structure Core 3D scanner, a structured-light 3D scanner using a projected infrared pattern to capture the 3D shape of an object by measuring the deformation of the pattern on the object's surface, essentially creating a dense depth map with good precision. The members also had access to multiple Apple devices and their LIDAR capabilities (including a 2020 iPad sensor) After a trial stage, the team decided to use the Apple sensors for this project.

Figure 8. Painting in concern

This section covers the results of the scanning process. Both good and bad scans with issues were obtained. Figure 9 illustrates a group of 3 good initial LIDAR scans where there are no issues with the object, but there is noise around it, to be removed later. Each scan demonstrated quality mesh outputs.

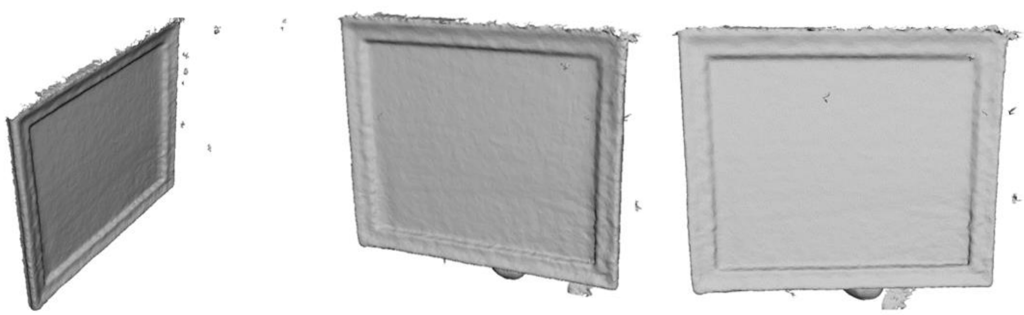

Figure 9. Good LIDAR scans

On the contrary, Figure 10 illustrates a problematic scan (a) and its failures relation to the original color image (b). Even there were issues with the scan, there were also good aspects to it, including the scanner and its app (3D Scanner App) were able to pick up the trees and bushes with clear depth from the canvas identifying these patterns with accumulated paint. However, LIDAR software struggled to pick up depth from floor to painting and grabbed frame causing the visible issues in Figure 10 a.

Figure 10 a) A problematic scan b) matching color image

Figure 11 below demonstrates the finished full-color scans. However, these scans are not yet ready to be printed. As this paper being written, the team was planning to convert the scan results (STLs or (surfaces files) to watertight manifolds for 3D printing to replicate them including the painting in Figure 12.

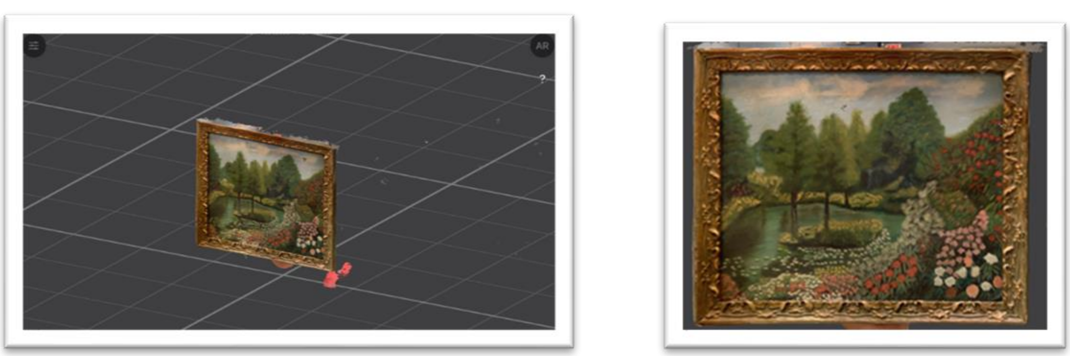

Figure 11. Finished full-color scans

Figure 12. Most recently scanned painting with pronounced paint brush strokes

Student Feedback

This section includes direct accounts of the two students who were involved in the most recent process of digitizing paintings, who are also the co-authors of this paper:

- “To begin, I learned how to use different 3D scanners each take different amounts of time to do. The first time I did a 3D scan I used an IPad and it took 30 minutes to attempt to get most of the detail, but it did not because it was a free software that tried its best but gave close to the results we were looking for. I then used EinScan in the Biomed Engineering Lab. With this scanner it took roughly 30 minutes to get the whole painting scanned and another 1 hour and 30 minutes to fully finish a perfect scan. We did a third test with just capturing the painting which took 15 minutes and only about 45 minutes total to finish everything. The program relies heavily on RAM space and if we had 64GB at least we would be able to 3D scan most objects. As of now we are unable to use high quality for a long period of time as it uses too much RAM to the point it cannot process it. The first scan was on high for everything and without me pressing certain buttons then waiting for some RAM space to free up it would not work. The third of just the painting was on high and did not take up as much space since we did not get any of the table. For the second test we tried medium quality but it was not to our liking so we deleted it as it did not show the brush strokes for the painting. In conclusion, I feel like I learned a lot about 3D scanning from doing these scans of paintings and should be able to use multiple different 3D scanners and software tools.”

- “It was a fantastic experience using an industrial 3D scanner. It allowed us to work through challenges and troubleshoot the technology when applied to a purpose beyond its intended purpose. We encountered a number of unexpected issues, such as filling up the

RAM in the workstation, ensuring that sharp edges and corners received extra attention, and making sure the room lighting was optimal without creating glares or shadows on the object being scanned. This process taught me that engineering can be integrated into a wide variety of fields, not just STEM or tech-related projects.

I also realized the importance of cross-disciplinary connections. By reaching out to other departments to learn about their areas of expertise, we were able to expand our understanding. As engineers, we often find ourselves separated from those in the humanities, but this project proved how valuable collaboration across different fields can be. Additionally, we explored new applications of 3D printing, gaining valuable experience in the gap between scanning an object and preparing the file for printing. There are several crucial cleanup steps in between that are rarely discussed, and I found that to be an essential takeaway from this experience".

Conclusions and Future Work

This paper is about teaching engineering students non-industrial 3D scanning work, for adding to their versatility. The students' materials, optics, and art knowledge are also enhanced due to being involved in a cross-disciplinary project like this. They also become better 3D scanning technicians and engineers, and can easily scan all sort of objects and manipulate resulting data. With this project, the students showed gains in the following ABET student outcomes:

- SO1: an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. *Students had to overcome scanning and printing issues to complete their projects.*
- SO4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. *Students were exposed to use of 3D scanning in an ethical way and its impact on the society in terms of culture preservation. They were also exposed to Intellectual Property laws within their ENGR 4801 Rapid Prototyping and Reverse Engineering course they took earlier.*
- SO6: an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. *To be able to solve their problems, students experimented, including the selection of a better 3D scanner.*
- SO7: an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. *Students were able to carry out, with little supervision and training from the lead author.*

Future plans include using LIDAR feature of the Apple devices in scanning 3D industrial objects and having access to RLP and MS-OCT Technology, employing some of these scans in multiple reality (MR) applications including augmented reality (AR), virtual reality (VR), or hybrid reality (HR). In terms of the continuation of this work, the team will 3D print some of the painting scans after obtaining the watertight STL manifolds, and also further study brush strokes closely.

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