Reconstruction of a Nineteenth Century Plaster Piece Mold and Recreation of a Casting

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Abstract

This paper describes the 3D documentation of an incomplete nineteenth century plaster piece mold, the techniques used for the virtual replacement of missing mold pieces and the virtual recreation of the lost cast. The work by noted nineteenth century American sculptor Hiram Powers, is a rare surviving direct link to the artist's creative process. Scan data collected from the Powers mold were used to virtually recreate the lost pieces of this mold. The virtual reconstruction will be used to fabricate the lost pieces and provide a physical copy of the mold for proper storage of the original as well as for display and public programs. A recreation of the cast will also be fabricated from the mold data. 3D imaging by structured light scanning was used to record all spatial data for the mold pieces. This data was then processed further to virtually replace the lost pieces and to extract the piece mold surface data. This mold surface is assumed to be the same as the surface of any casting from the mold. Virtual reconstruction of a lost cast from the artist's mold results in a unique opportunity to view Powers' work as it was originally intended.

Key words: 3D scanning reverse engineering, structured light, replication

1   Introduction

Hiram Powers (1805-1873) is considered one the America's great neoclassical sculptors. His works were popular in his time and remain so today.[1,2] The Smithsonian American Art Museum (SAAM) has one of the most comprehensive collections of Powers' work featuring major sculptures in marble, as well as preparatory works from his studio. The plaster piece mold (figures 1 and 2), Mold for Positive Cast of a Child's Hand (ca. 1851) discussed in this paper is a rare surviving mold for a preparatory work.[3] There are no surviving casts known. As such, it gives insight into Powers' study for other finished works. The example being described in this paper is fragile and has lost two of its eight parts, making it difficult to store or move safely.

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[1]. Lynne Ambrosini and Rebecca Reynolds, *Hiram Powers: Genius in Marble* (Cincinnati: Taft Museum of Art, 2007).

[2]. Donald Reynolds, review of *Hiram Powers: Vermont Sculptor, 1805-1873*, by Richard P. Wunder, *The Art Bulletin*, December 1992, pp.687-690.

[3]. Luce Foundation Center for American Art. Cast of an Unidentified Baby's Left Hand Pressing Down. Smithsonian American Art Museum.

http://americanart.si.edu/luce/object.cfm?key=338&artistmedia=0&subkey=440.

Figure 1. Mold of a Child's Hand, Hiram Powers, plaster
Smithsonian American Art Museum
Museum purchase in memory of Ralph Cross Johnson
1968.155.173A-D (photo: SAAM)

Figure 2. Mold of a Child's Hand, Hiram Powers, plaster
Parts 1, 2, 5, 6, 7, and 8 are extant. Parts 3 and 4 (seam lines indicated) were reconstructed.

The initial request from SAAM conservators sought to determine if the scan data could indicate whether or not a cast from the mold existed in the collection. In addition, the conservators wanted to explore the feasibility of recreating the lost mold pieces to stabilize the assembly. Methods traditionally used to cast from an extant mold or otherwise copy a surface (such as flexible rubber mold making) were deemed too intrusive and thus likely to compromise the surviving mold pieces.

The authors determined that 3D imaging would be a feasible alternative to the traditional methods of molding and casting, given the fact that current 3D methods are non-contact, and may only require minimal handling of an object. The Museum Conservation Institute (MCI) has a portable structured light scanner that can safely produce precise, high-resolution spatial data, as well as color information, from collection objects. The collaboration with Survice Metrology brought engineering and data processing expertise to the project for the cast recreation. The familiar term "reverse engineering" can be applied to this step of the processing of the Powers' data: reverse engineering uses existing material to reproduce a new part. This is a common task in commercial industry, where research into a competitor's product can involve virtual disassembly, analysis, testing, and copying. In the Powers' case, however, fewer constraints were found. The task for MCI and Sur9ice Metrology was to virtually refit the piece mold surfaces together and then fill the voids: the voids in this case are the missing pieces. Once completed, this would also allow creation of a virtual copy of the cast that could be used by SAAM conservators and curators to compare to known works by Powers. The SAAM education department also became interested in a hard copy of the mold and cast for use in their public programming and display. To serve this end, a physical copy of the cast will be created from the virtual data.

2   3D imaging of the mold

3D scanning has been reviewed in an earlier article[4] (Wachowiak and Karas in press). The references serve as excellent background on the subject, and the MCI scanner was described in detail. The portable structured light scanner, operated by MCI conservators, was set up in available locations in SAAM, all of which had no windows and controllable levels of artificial light. Ambient light is best kept at low levels during scanning, since too much extraneous light leads to poor 3D data collection (the scanner's internal

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[4]. Melvin Wachowiak and Basiliki Vicky Karas. In press "3D Scanning and Replication for Museum and Cultural Heritage Applications," *Journal of the American Institute for Conservation.*

lamp should be the dominant light source). Scanning was carried out on a table with a black cloth covering to improve contrast. The plaster pieces were moved during scanning by conservators wearing nitrile gloves, and set into position using foam wedges when required.

3   Equipment

A Breuckmann triTOS™ (GmbH) structured light scanning system[5] belonging to MCI was used to scan the Hiram Powers mold. The key components of the triTOS™ scanner are the controller, sensor bar (5cm long), the projector and camera. The sensor bar, projector and camera component are mounted on a tripod. The camera lenses and the sensor bar on the triTOS™ are interchangeable to give varying fields of view. The use of a 5cm sensor bar and 100mm lenses allowed the mold pieces to be scanned with about a 10cm field of view on the diagonal at a working distance of 39cm. The theoretical volume of each scan is 80mm x 60mm x 40mm high (the xyz dimensions). The scanning resolution in this configuration is no less than 60μm. The triTOS™ system software was run on a PC notebook computer.

4   Technique

Structured light scanning projects a sequence of organized patterns of structured light, for example, grids, dots, or stripes, on a scan subject as it is simultaneously photographed using a digital camera that is specially aligned with the projector. The captured images show the distortion of the projected light pattern as it strikes the scan subject. Data is acquired at about 1 second per view. Associated structured light software processes the projected light pattern distortion and color information to generate point cloud data. Because the point cloud's (XYZ) range and (RGB) color values are recorded together, the color information is registered exactly with its corresponding 3D point. While the color data was of little

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significance for the work requested, it was collected to form a more complete documentation. The triTOS™ system has a triangulation angle (projector to subject to camera) of 20 degrees. This generates fewer scans and better data capture on objects with complex geometry, for example areas of high relief on an object's surface. 3D imaging of the Power's piece mold was completed in approximately 8 hours.

5   Data post processing

The raw data from the Powers piece mold was retained in two forms. An unprocessed copy of the original scan data (raw data) was retained for the record. Processing involved the subtraction of noise, alignment and merging, and hole-filling (figure 3).
1. The triTOS™ system software (Optocat 2006.2) was used to delete extraneous noise and major overlaps and misalignments in the raw data. The data was then re-aligned, merged and exported as a binary PLY file format. PLY file formats are designed to store 3D data with a variety of properties such as color information, surface normals, and texture coordinates, and allows for the data file to have different properties for the front and back of the polygonal mesh. A polygonal mesh is generated by "connecting the dots" of the measured spatial data (each *xyz* coordinate in space) to produce a solid 3D graphic view of the scan data.
2. Rapid Form™ (2006) 3D graphic software was used to import the binary PLY files created in Optocat 2006.2. The hole-fill function in the software was used to close gaps in the mesh. Although this step can be automated, this software allows the operator to determine which holes to fill. This operation is "intelligent" because information from the surrounding mesh is used to close a void, i.e. if the triangle mesh surrounding a hole curves, then the hole-fill function will continue the curve. Evidence of hole-filling is clearly visible as a uniform mesh and can always be identified in the data in this viewing option. Larger fill areas are also recognizable as smooth patches when viewing the data as a solid.

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[5]. Breuckmann GmbH. "triTOS - The Third Dimension in Arts & Cultural Heritage." http://breuckmann.com/index.php?id=tritos&L=2
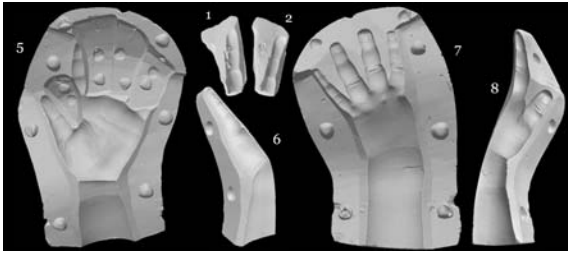
Figure 3. Solid views from STL files of all existing pieces of the mold, after post processing.

Processing resulted in two data files for each of the six extant pieces of the mold: one STL format file which contains only spatial data, and one PLY format file which contains color data. Both are standard formats that can be used in many standard programs. The files can be viewed using engineering software, a bundled Rapidform viewer[6], or others such as the PolyWorks free viewer[7]. All but the engineering software have limited functionality, but basic viewing and movement of the objects can be accomplished.

It became clear while viewing the data that the cast is not in the SAAM collection. Through manipulating the virtual lighting in the 3D viewing software to create changing virtual lighting angles, the illusion of a solid cast was created. Virtually inverting the normal light and shadow to render the mold as a positive space, rather than negative provided a very clear image of a child's hand. Precise volumetric and surface area measurements taken from the scan data corroborated the initial visual inspection: the virtual hand is larger than the casts of children's hands in the collection.

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[6]. Inus Technology, "Free 3D viewer, Rapidform® EXPLORER™ release," http://www.rapidform.com/portal/default/Products/index?Category=Products_RapidformEXPLORER_Overview

[7]. InnovMetric Software Inc., "PolyWorks/IMView," http://www.innovmetric.com/polyworks/3D-scanners/viewer.aspx?lang=en

6 Virtual reconstruction of the mold

The scan data was processed and modified in the industrial software PolyWorks/Modeler. The software is designed for reverse engineering applications, inspection, comparison and data clean up. Since the mold was not scanned in one piece (thus giving the outer constraints), it needed to be assembled virtually. Each data set for the scanned parts was inserted into a single file. The assembling of the parts was done in PolyWorks. Matching points were carefully selected on each piece of the virtual mold. The red dots in figures 4a and 4b are examples of these alignment points. This careful selection is not typical and requires more work than a fully automated assembly. However, because of the complexity of the surface, the results are much better than by automation. The typical alignment process is semi-automated in PolyWorks, and is accomplished by comparing curvature. An example of this type of alignment can be seen in figure 5. The purple section of the figure is what it looks like when the gray piece has been aligned properly.
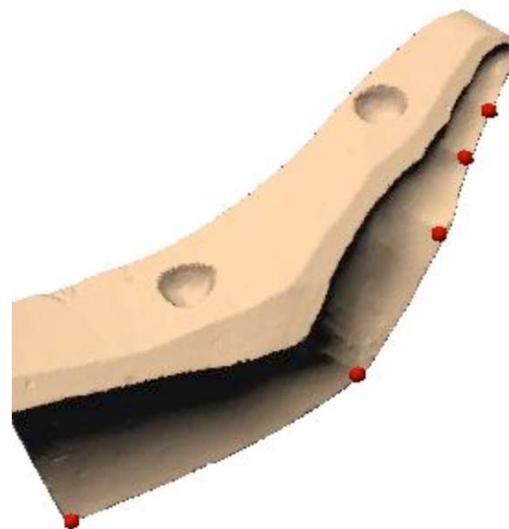

Figure 4a. The little finger section (6) with one set of alignment points for semi-automated alignment.
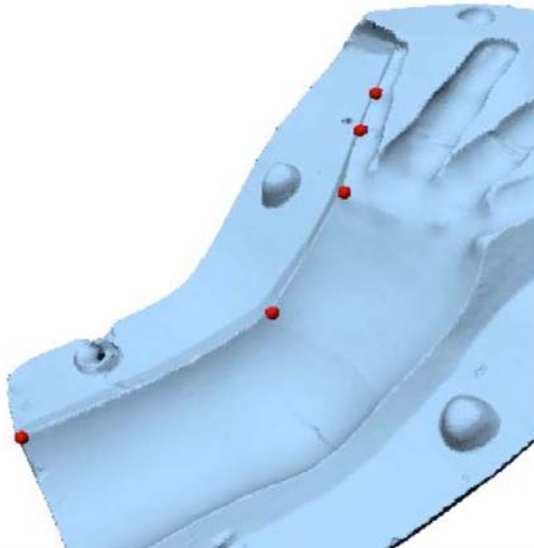
Figure 4b. The back of the hand (piece 8) with second set of alignment points.
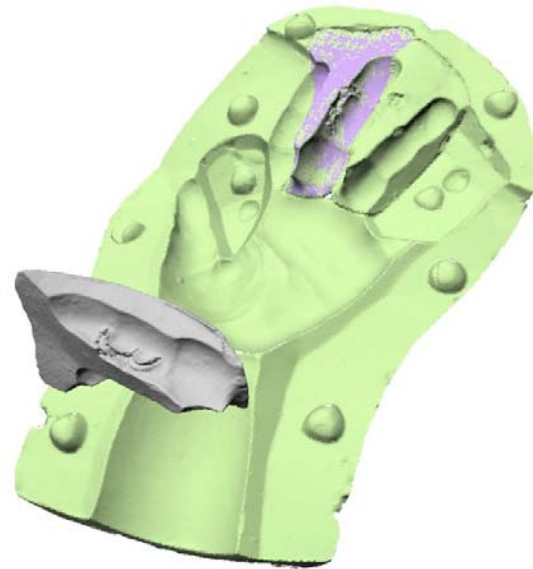

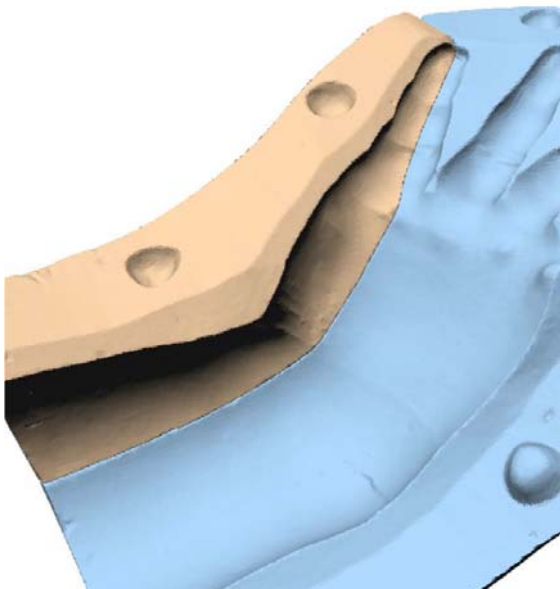**Figure 5.** Sections 1, 2 and 5 assembled.

Figure 4c. sections 6 and 8 joined

Figure 6. Inverted data from mold interior renders a positive virtual cast.

7   Recreation of the cast

The creation of a cast of the mold was the next phase. Simply stated: what used to be the inside of the mold now becomes the outside of the cast. Figure 5 is the opposite of figure 6; virtual mold now becomes virtual cast.

By first copying the mold, trimming all but the hand and then turning it inside out, the transformation is nearly complete. The image of the cast was much easier to work with than the image of the mold. A copy of the cast was saved for comparison to the mold during later data manipulation to ensure that the virtual cast stayed true to the virtual mold.

At this point, it was time for the virtual artistry to begin. There were two pieces of the mold missing; half of the little finger and ring finger, and half of the crook of the hand. These pieces had to be made manually in PolyWorks. The little finger and ring finger were much easier to reproduce because they could be modeled as scaled down and mirrored pieces of other fingers. For example the tip of the little finger was modeled as 75% of the size of the ring finger. To do this a copy of the mold data was used, then trimmed of all but the tip of the ring finger, scaled to 75% size and then aligned to the tip of the little finger. Each section of the little finger was modeled with a different scale factor applied to the ring finger and then aligned. The ring finger was produced by first copying, and then creating a mirror image of the existing half finger. Next, different sections of the thumb side were aligned to the little finger side. The same process was tried for filling in the thumb but with was not successful. What did work as a starting point for the thumb reconstruction was taking the image of it from the back side of the hand and putting it on the palm side of the hand. This yielded a starting point from which to build. From this starting point moldable surface patches were mapped. PolyWorks then allows the user to hand mold the model by moving control points on the mapped surfaces. The blue patch is a surface that is mapped to the model under it. The three-axis system surrounded by a wireframe sphere (figure 7) is a control point that can be moved in any direction dragging the surface with it. This method made the most convincing hand over all

but it still is not perfect: the geometry was proportional but the model is too smooth to be believable. In this way however, the areas of fill are visible by careful inspection. No further work was undertaken at this time.
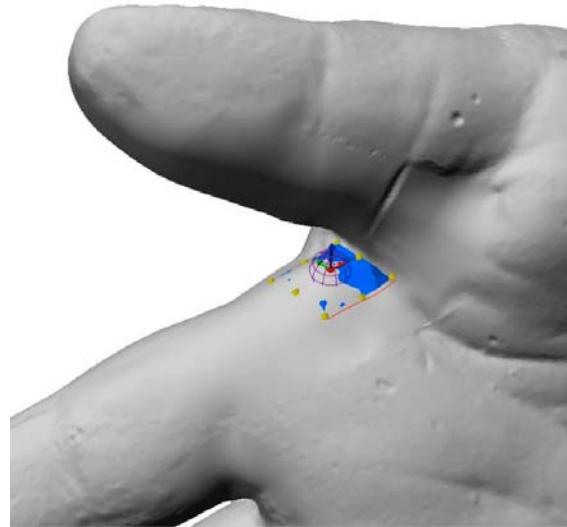

Figure 7. Control point used for hand modeling of the mold.

After the missing fingers were modeled, the gaps between the mold pieces needed to be filled. This was done through careful clean up and simple fill commands in PolyWorks. At this point a complete cast of the mold was made but a completed mold still needed to be constructed. The cast model was inverted and trimmed leaving only the reconstructed parts of the model, i.e., the thumb and the two missing fingers. These were separated into different models which, at this point, were just skins as seen in figure 8. Then the adjoining half of the mold was reduced slightly, inverted, and copied to fill in the remaining skin.
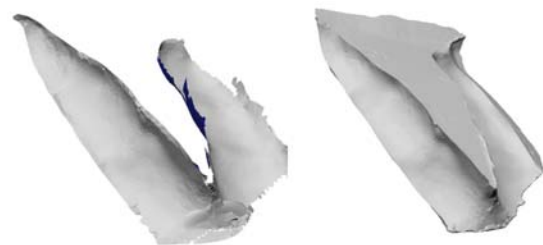

Figure 8. Left side: finished cast surface but empty mold area; Right side: restored mold.

The mold was now finished but included minor and major imperfections, all a part of the artist's original process, as well as wear and tear over the years. The reconstructed mold had large damaged areas on both sides of the middle finger and a smaller one on the side of the ring finger. The imperfections are important to preserve for historical purposes, but can be distracting to the eye and do not reflect the artist's original intent. For this reason, one data set of the mold and cast were retained without further editing. This compliments the original scan data as documents of the state of the object. New copies of the mold and the cast were smoothed by cutting out the imperfections and modeling new sections through the same reconstructive methods mentioned for the crook of the thumb. Figure 9 depicts the before and after view of this process. The parting lines of the piece mold can be seen, but the surface was smoothed, as it would have been in the studio.
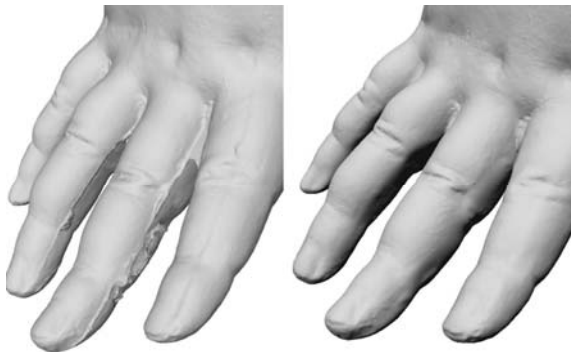

Figure 9. Left: Cast with original imperfections; Right: Cast with imperfections removed.

8   Conclusion

3D imaging is becoming increasingly more common as a curatorial and conservation tool in the cultural heritage field. This paper demonstrates that applications go beyond documentation, and shows that 3D data can be used to create lost components from an art work and thus offer a unique opportunity to reunite that work. Using the complete data set to create a new negative, a virtual cast from the mold, is yet another way to experience the artist's vision. When the material integrity of an existing art work is too fragile to reproduce using traditional methods 3D imaging offers an attractive alternative which enriches our experience and understanding of a work of art and facilitates audience interaction with a piece. The Powers mold is an example of how 3D data can be used for the conservation and restoration of an art object. In addition, the data offers a virtual and physical experience with the piece not possible with the original. Finally, by using the scan data, we anticipate a "return to reality," that is, when the physical model of Powers' mold and cast are produced by milling and stereolithography.

Acknowledgements

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