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Seeing the unseen. The Selene project for 3D digitization of Cultural Heritage

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Abstract

Funded by the Helen Hamlyn Trust, ARCHiOx – Analysis and Recording of Cultural Heritage in Oxford, is a collaborative project which has united Oxford University's Bodleian Libraries and the Factum Foundation. The Selene Photometric Stereo Scanner was conceived and developed by the latter and has, for the last three years, been piloted at the Bodleian Library. This technology has been used to reveal near-invisible text and artwork from originals from across Oxford University's collections. Renders created with the Selene PSS, have revealed what is difficult or impossible to record through conventional photography, and have allowed for the creation of physical facsimiles. This paper serves to demonstrate how Selene recordings have assisted in the research of cultural heritage originals and natural history specimens.

Introduction

The importance of capturing the textural surface of special collections material has been made abundantly clear from recordings created using photometric stereo imaging. The materiality of manuscripts, books, printing plates and artwork can tell us a huge amount about who made them, how they were made and about people's interactions with them since they were made.

Since 2022, the Selene PSS has been used extensively to capture a selection of material from across the collections of Oxford University's most prestigious institutions. It has also been adopted by institutions elsewhere in the UK, Europe and the USA. The recording system and its software were designed by Factum Foundation's Head of Technology, Jorge Cano.

Using a principle called photometric stereo 3D surface data from a small original or sample is acquired through the capture of just four 2D images. For each image tile, high resolution data is captured in seconds and is processed in less than a minute. This immediacy allows for the recordings to be consulted alongside curators, conservators and researchers. Working in this collaborative way has been mutually beneficial, insuring that the renders generated from the recording are made with the benefit of scholarly context.

Through documenting surface markings which may have been observed by researchers, but never before adequately imaged, ARCHiOx recordings have served to prove researchers' assertions and assist in our understanding of how and when our cultural heritage originals were manufactured.

Photometric stereo renders reveal surface topography through shading and in the absence of the original's tone and color. This principle has significant advantages over images made using traditional techniques for the capture of surface topography. These advantages can be observed through the comparative recordings shown in *fig.1*, an aquatint print from Francisco Goya's *Los Caprichos.*

While photography illuminated from a single, raked light is capable of revealing surface detail in the substrate, the ink on the print's surface distracts, and in some regions prevents entirely the researcher from being able to analyze the texture across the entire print. Photometric stereo renders have the considerable advantage of being able to exclude the print's tone and color entirety, as if consulting a plaster impression of the surface of the paper, illuminated from any given angle with a torch. Given that the shadows and highlights which reveal this micro-topography are computer generated rather than lit conventionally from a single point, the render has the additional benefit of being evenly illuminated across the entire plane.

Transmitted light photography, commonly used as a method for capturing paper structure and watermarks, involves the capture of a substrate as light passes through from beneath. *(fig. 1a)* This is an effective method when recording originals with little text or illustration.

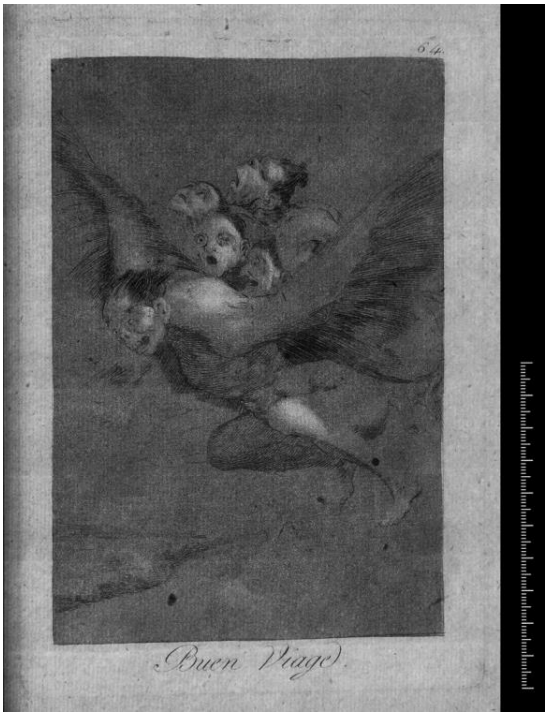


***Figure 1a**. Transmitted light image. Plate 64, Buen Viage, from the Bodleian Library's volume of Francisco Goya's Los Caprichos Bodleian Library, Douce Prints 25*

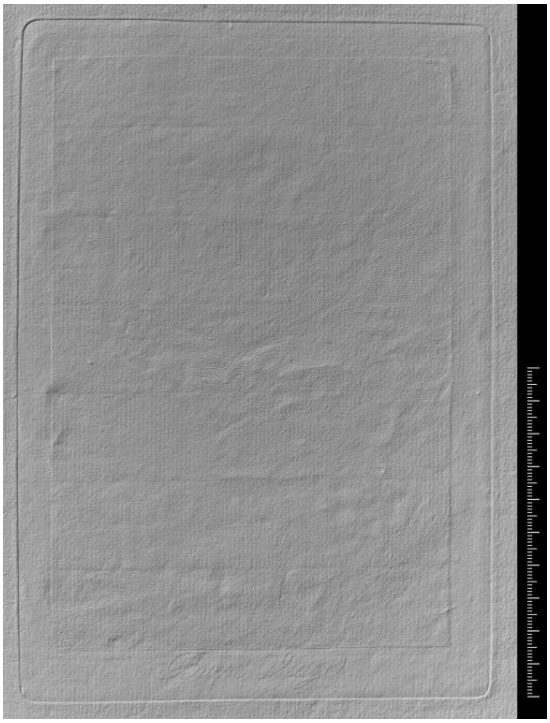


***Figure 1b**. Greyscale render from photometric stereo recording. Plate 64, Buen Viage, from the Bodleian Library's volume of Francisco Goya's Los Caprichos Bodleian Library, Douce Prints 25*

Given the abundance and density of ink applied to the Goya print however, much of the paper's materiality is difficult to discern. In contrast, a photometric stereo recording allows the researcher a clear view of the structure of the paper in regions that are both un-inked or printed. A photometric stereo recording has an important additional benefit in that it can reveal features including chain lines, laid lines and watermaraks, even in cases where the original is pasted to a support. *(fig. 1b)* Making a clear recording with either transmitted light or beta radiography in such cases would be impossible.

In addition to the visual representation of surface topography, the data generated by the Selene PSS contains actual 3D information of the object, presented as a gray scale depth map. This data permits the measurement of details like incisions or minute marks on the surface (both as positive or negative relief). The data also allows the researcher to create crosscut views and, especially, makes it possible to prototype surface in physical form, with digital fabrication techniques like 3D printing or CNC milling.

Methodology

Reflectance Transformation Imaging, or RTI is a widely adopted technique for cultural heritage imaging. RTI recordings permit the end-user to relight the recorded surface of an original as if holding a torch to its surface. Being able to interact with the recordings in this way may allow the researcher to reveal useful information such as tool markings or surface substrates on which the works were made. In order to acquire the RTI recording, the original is placed on a stage under a hemisphere containing dozens of LED lights and a series of aligned photographs are captured from above, each illuminated from a different position.

The methodology used by the Selene PSS to capture information is similar in that it uses a single camera position and multiple lights to acquire surface data. While RTI is extremely effective, the photometric stereo methodology which the Selene PSS employs has several notable advantages.

Firstly, capture and processing are considerably faster, and far less data is generated. For each image tile, the Selene creates just four input images - perhaps 10 to 20 times less than would typically be created with an RTI recording system. Given that the Selene doesn't need to capture or process as much data, it can afford to use a high-resolution camera sensor. Originals are captured at a minimum of a million pixels per square inch, but through using higher magnification lenses, this resolution can be increased significantly.

3D surface data is processed from the four source images using the Selene's proprietary software. The resulting texture maps encode the topography within standard image files. However, instead of simply storing a color for each pixel as would be the case with a digital photograph, the relative height and angle of the surface are recorded at each pixel, assigned by a tone or color.

While the capturing process of the Selene PSS is similar to RTI, the innovative processing software makes it possible to extract actual 3D information, opening the door to a whole new range of possibilities for studying, sharing and even re-materializing the scanned surface. Where RTI provides a visualization tool, Selene PSS also obtains measurable depth information.

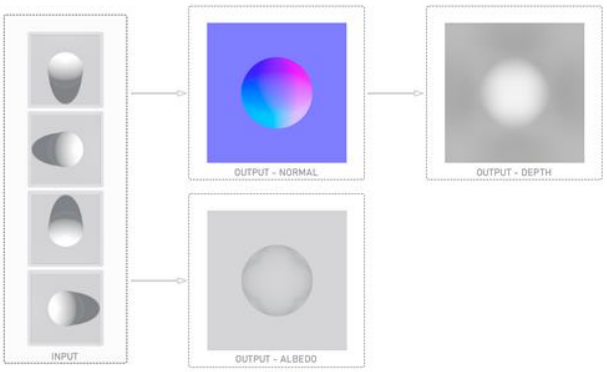


***Figure 2**. The photometric stereo principle, as used by the Selene PSS. The four input images are processed into two texture maps – a normal map which encodes a vector at each pixel and a depth map which encodes relative height at each pixel. In this way, the original's surface is mapped. From the same source images, an albedo map, which reveals color without shadow is created in the Selene's processing application.*

Having completed the processing with the Selene PSS processor, rather than needing to load these files into a specific application to view and render the recording, the texture maps can be explored using a number of software products and plugins. By loading a depth map into a GIS software application, the recording can be lit from any angle or height just as can be achieved with an RTI recording, but in addition it is also possible to alter the viewport. Though the original is recorded from above, the angle and altitude from which we view the recording can freely modified. This allows the researcher to navigate the recordings in an unrestricted and extremely useful way. Using the same application, it is also possible to select a profile through a region of the recording and make comparative measurements across its surface.

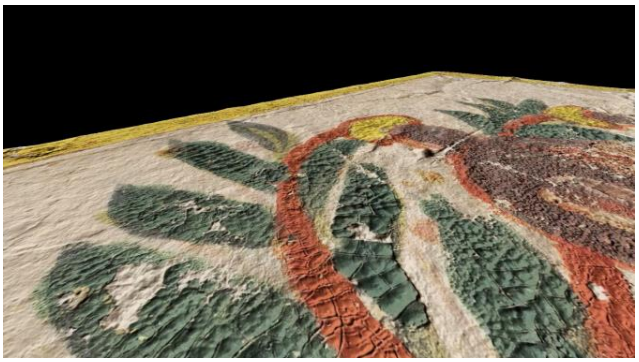


***Figure 3**. A composite render of the surface of the Bodleian Library's Kitāb Gharā'ib al-funūn wa-mulaḥ al-'uyūn ('The Book of Curiosities') – a C12th-13th Egyptian manuscript. Through being able to relight and view the surface of the page from any angle or height, the researcher, curator or conservator can discern important information regarding the materiality of an original. In this case, flaked and damaged pigments on the surface of the page are clearly visible. Bodleian Library, MS. Arab. c. 90*

Representing the three-dimensional surface of an original in a single, static image poses a unique challenge when making renders. No two originals are alike. Differences in color, tone and texture may necessitate renders being made using a variety of settings and methodologies. Given that the texture maps created by the Selene software can be processed in sophisticated GIS applications, a variety of shader options and blending algorithms can be utilized in order to best represent the surface of the recorded original. As well as defining where shadows and highlights fall in order to define the surface, it is also possible for the researcher to include some of the original's color in the render. In doing so a *composite* render can be made. This is a useful derivative for research, as a surface render in the absence of any of the original color can be difficult to navigate. A variety of blending modes and opacities can be utilized in order to create the composite render, either to enhance features which are of particular interest to the researcher, or to best represent the materiality of the original.

***Figure 4**. Left to right – albedo map, shaded render and composite render. Estudios de cabeza de anciano, Antonio de Pereda. C17th oil on canvas. Instituto Valencia de Don Juan. Recorded by Santiago del Bosque Arias.*

In addition to capturing actual 3D information, one of the fundamental advantages of the Selene over many RTI systems is that it permits the recording of large format originals. Typically, the dimensions of the original are limited by the size of the stage beneath the RTI system's hemisphere. The Selene is able to create large, multi-tile recordings in a highly efficient manner. The camera and flash unit assembly can be programmed to move over the surface of the original. In this way, it is possible to capture large originals such as master paintings and maps. A portable version of the Selene has also been developed to enable vertical recording. Crucially, this allows for the capture of originals in situ. The large, Elizabethan portrait shown in *fig.5* was captured in a reserve, removing the need for the painting to be transported to an imaging studio. Provided that the original is captured from the correct distance, the recording can be captured and processed using a

similar workflow. Given that custom flash units rather than LEDs have been adopted for both the portable and studio versions of the Selene PSS, the recording can be made without the need for low level ambient lighting to be turned off during capture. This makes the portable version of the Selene an important solution for the acquisition of surface data as it permits efficient capture of artworks or artefacts with far fewer logistical concerns for the museum or gallery to navigate.

***Figure 5**. An in-situ recording of a large, Elizabethan Portrait. The portable version of the Selene PSS permits photometric stereo recordings without the need for the work to travel to an imaging studio. Portrait of an unidentified woman, end of 16th century. Bodleian Library, LP 56*

During the course of the project, developers from Factum Foundation have explored how photometric stereo recordings can be used to create physical facsimiles of collections material. This is of great importance given the understandably limited access permitted to many of an institution's most treasured works. Facsimiles can be consulted in place of originals, permitting an unrestricted experience to the researcher. 3D prints can be made by simply converting the texture maps into common 3D printing formats. Gray scale depth maps in TIFF formats can be used to make Elevated Prints; exporting to STL format will also facilitate 3D printing.

High-resolution 3D recordings of the Gough Map of Great Britain - the earliest map depicting the British Isles, have been used for two purposes: to assist in confirming its date, and for the production of a 3D facsimile, the latter allowing for academic study while ensuring the preservation of this unique and historically important artefact.

***Figure 6**. A double-sided, 1:1, 3D printed facsimile of The Gough Map of Great Britain. Dating to the 14th century, the Gough Map is one of the earliest maps to show Great Britain In a geographically recognizable form. Bodleian Library, MS. Gough Gen. Top. 16*

Results

Through close collaboration with curators and researchers, the following examples recorded with the Selene PSS have directly benefitted academic study.

Recordings of a series of High Renaissance Drawings made by Raphael, Michelangelo and Giulio Romano, held at the Ashmolean Museum, have uncovered markings which reveal the artist's preparatory and copying techniques.

***Figure 7**. Detail from a drawing by Raphael, from 1506. The composite render made by combining the albedo map and surface render reveals the artists' use of blind stylus for outlines, anatomical notations, felt marks and pouncing. Ashmolean Museum, Standing figures in a Pieta, recto, Raphael*

Renders created from recordings captured with the Selene PSS have revealed what is considered to be the poet and artist William Blake's earliest portrait – a tiny, informal engraving discovered on the reverse of an 18th century copper printing plate. This design would have been engraved while the teenage Blake was apprenticed to the master engraver, James Basire.

***Figure 8**. No bigger than a fingernail, this tiny engraved face is considered to have been engraved by a young William Blake. Barely visible due to the degradation of the copper plate and being obscured by a line of repoussage, It was discovered while studying a recording made using the Selene PSS.*

A series of recordings captured at the Oxford University Museum of Natural History have demonstrated how photometric stereo recording can not only been used to document works of art, but also how it has enormous potential for the documentation and research of natural history collections. Over three days, the Portable version of the Selene PSS was used to capture dozens of specimens from the Museum's earth and life collections. These included examples of fossils, feathers and animal skin.

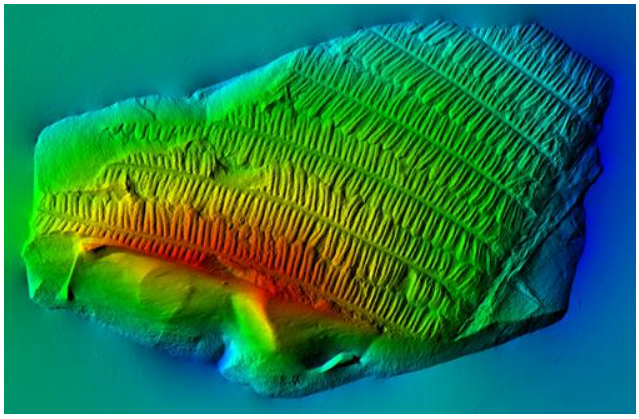
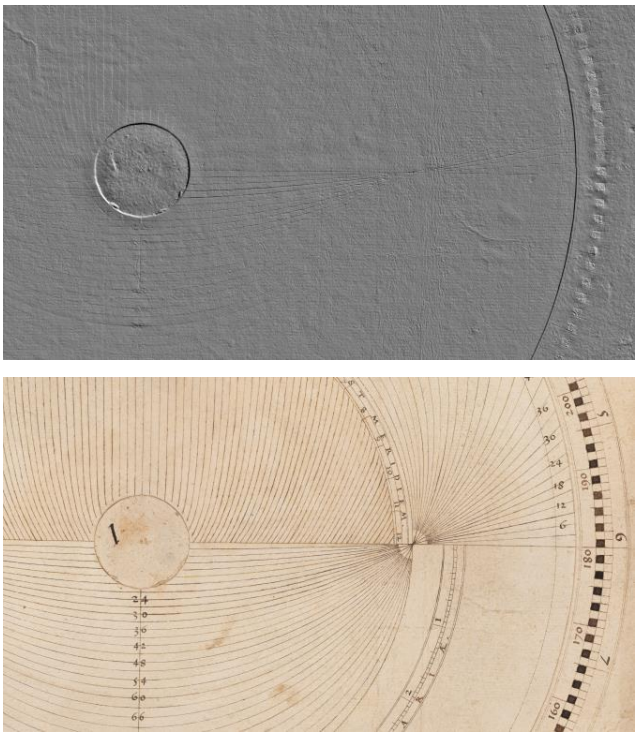


***Figure 9**. A render from a photometric stereo recording of a fossil from the collections of the Oxford University Museum of Natural History. In this case, a shader which represents height through color has been utilized. OUMNH E4853*

From the collections of Oxford University's History of Science Museum, a pasteboard astrolabe, dating to the 1550s and once used in the Radcliffe Observatory was recorded, revealing perhaps the most abundant use of preparatory measuring marks and stylus guidelines thus far recorded for the project. These markings are completely absent from conventional photographs.



***Figures 10a and 10b**. Above: A shaded render showing meticulously measured and incised stylus impressions in the surface of a pasteboard astrolabe. The incisions served as a preparatory guide before the maker committed their design to ink. Below: an aligned color image. History of Science Museum, MS. Radcliffe 74*

Conclusion

Since 2022, the aim of ARCHiOx has been to record a wide variety of cultural heritage material and natural history specimens using the Selene PSS, in order to ascertain what photometric stereo recordings are capable of revealing. The conclusion is that the recordings reveal a great deal. Through the recordings which have been made, we have established how and when artworks were created, enhancing our ability to improve provenance. We have taken measurements which have aided us in determining the hand of an artist or the identification of a species, and we have created facsimiles which allow for unrestricted study while ensuring our collections are protected.

As well as the technical developments involved in the capture of this important data, consideration has also been given to the solutions required for the publishing of photometric stereo recordings. Factum Foundation and the Bodleian have collaborated

on solutions which permit viewing and interaction of Selene PSS recordings within the IIIF supported image-viewer, Mirador. Developments include an online plugin which allows the researcher to relight the surface of a recorded original.

Though the Bodleian Libraries was the first institution to use the Selene PSS, the recording system has now been adopted by other prestigious libraries and museums. Among these, the British Museum, Princeton University Library, Instituto Valencia de Don Juan, and the John Rylands Research Institute and Library.

Photometric stereo has proved to have enormous potential for the highly-efficient recording of cultural heritage collections, ensuring their preservation and helping us to understand them more fully.

Author Biography

John Barrett is Studio Manager and Senior Photographer for the University of Oxford's Bodleian Libraries. Since 2005, John has recorded manuscripts, artworks and objects from the collections of Oxford University's libraries, museums and galleries. His images and research have been published in numerous publications. His work involves the development of new methods of recording special collections material. John is Technical Lead at the Bodleian for ARCHiOx (Analysis and Recording of Cultural Heritage in Oxford).

Jorge Cano, Head of Technology at Factum Arte and Factum Foundation, has forged a multidisciplinary career merging art and technology. Specialist in 3D recording, image filtering, and human-computer interaction, he has created various scanners and data processing tools—including the Selene PSS used by the Bodleian Library and the Selene Circle. He studied Cartography at the Polytechnical University of Madrid and later specialized in 3D, real-time interaction, and software development at the Istituto Europeo di Design.

Carlos Bayod Lucini holds a PhD in Art History and Theory (UAM, 2022) and an MS in Architecture (UPM, 2010). As Project Director at the Factum Foundation, his work is dedicated to the development and application of digital technology to the conservation, study and dissemination of Cultural Heritage. With 15 years of professional experience, Carlos has carried out hundreds of digitization projects in the world's main museums, collections and archaeological sites.

Costanza Blaskovic holds a Master's Degree in Contemporary Art History and Cultural Heritage Preservation from Ca' Foscari University in Venice and a Second-Level Master's Degree in Archival Studies from Macerata University. She specializes in digital preservation of Cultural Heritage, collaborating with both public and private institutions. Her experience spans various digital preservation projects, working with artifacts ranging from photographic prints to contemporary hybrid archives and incunabula

Santiago del Bosque Arias holds a Master's in Technical Art History from UNAM and a Bachelor's in Art History from Universidad Iberoamericana. He specializes in research, curatorial work, and technical art history, focusing on painting. He has collaborated with private and public institutions, contributing to exhibitions, publications, and teaching. His multidisciplinary approach enriches the study and appreciation of art through interactive exhibitions and academic dissemination.

Ana Carrasco-Huertas has a Bachelor's Degree in Conservation and Restoration of Cultural Heritage from the University of Granada and Master's Degree in Diagnosis of the Preservation State of Historical Heritage from the University of Pablo de Olavide (Seville). Since September 2021, Ana is a PhD candidate at the Department of Painting, Faculty of Fine Arts, University of Granada (Grant PRE2020-094823, funded by MICIU/AEI and FSE+). Her dissertation centers on studying, digitizing and virtual reconstructing archaeological and monumental coverings