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REFLECTED INFRARED AND 3D IMAGING FOR OBJECT DOCUMENTATION

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Imaging techniques inform the conservation, research, and understanding of museum collections. Two types of imaging techniques were examined in this study: infrared (IR) and three-dimensional (3D) imaging. Reflected IR imaging is well established as an investigative tool for conservation providing information about condition, materials, and manufacture beyond visible light documentation. Reflected IR imaging results in two-dimensional images, which are limited in how they represent 3D objects. Three-dimensional imaging techniques, such as white light scanning and photogrammetry, extend the possibilities of digitization by recording the geometry and texture of an object. Reflected IR imaging, photogrammetry, and white light scanning were used to document six objects from the Freud Museum and the Smithsonian National Museum of the American Indian. The present study provides examples of reflected IR imaging for enhanced detection of features of 3D cultural heritage objects; discusses the potential of integrating reflected IR and 3D imaging to more fully document features of 3D objects; and investigates two 3D imaging techniques, white light scanning and photogrammetry. The study assesses the two 3D imaging techniques, one more expensive and the other more accessible, to discover whether there is a significant difference in performance for the purpose of resolving the details recorded by reflected IR imaging.

KEYWORDS: *Infrared imaging, 3D imaging, photogrammetry, white light scanning, reflected infrared imaging*

1. INTRODUCTION

The emerging field of heritage science combines the humanities and the physical sciences to address the needs of the arts, archaeology, and natural science sectors through management, conservation, interpretation, and digitization. Digitization, imaging and documentation, for research and conservation is a pillar of this field. It documents condition, informs care, and increases knowledge of heritage objects when well designed and executed. Digital imaging techniques are generally non-invasive and portable, attributes that are priorities when working with heritage objects. Among these techniques, reflected infrared (IR) imaging allows the enhanced detection of features as seen in applications for paper and paintings conservation to detect underdrawings, observe compositional changes, differentiate materials, and enhance obscured or faded features (Warda et al. 2011). This information about condition, materials, and manufacture of objects can provide observations beyond what is documented in the visible range for two-dimensional (2D) and three-dimensional (3D) objects. However, features of 3D objects are not fully recorded with 2D images. Three-dimensional imaging can provide a better representation of 3D objects by documenting the geometry and texture, or color, of cultural heritage objects. Three-dimensional

imaging techniques including white light scanning and photogrammetry have been used for cultural heritage documentation for applications including research, conservation, replication, and exhibition.

1.1 REFLECTED IR IMAGING

IR radiation has been used for cultural heritage documentation since the 1930s when film sensitive to near infrared (NIR) radiation (up to ~900 nm) became available (Warda et al. 2011). IR imaging records the varying reflection, transmission, and absorption of IR radiation by the materials present in an object. Following the terminology outlined in Warda et al. (2011), *reflected IR* will refer to imaging that uses wavelengths in the NIR region (700–1000 nm) and corresponds with the sensitivity of IR films and digital cameras with silicon detectors, and *IR reflectography* (*IRR*) will refer to imaging that uses wavelengths in the shortwave infrared (SWIR) region (1000–2500 nm) and requires specialized sensors (Fischer and Kakoulli 2006; Warda et al. 2011).

Reflected IR imaging and IRR are established investigation tools for painting and paper conservation for detection of features beyond visible light documentation. Early reflected IR imaging included investigating the artist's technique to reveal guidelines (Keck 1941)

and to provide clearer documentation of a painting obscured by aging varnish (Rawlins 1938). Van Asperen de Boer (1969) extended the sensitivity of reflected IR imaging from NIR to SWIR by introducing the use of the Vidicon system as a tool for detecting underdrawings in paintings. Mairinger (2004) included applications of reflected IR examinations for graphic arts (drawings, prints, and illuminated manuscripts) and paintings to increase legibility of manuscripts, differentiate inks and pigments, detect compositional changes, and reveal underdrawings. As digital camera technology has evolved, IR imaging continues to develop. Falco (2009) presented the use of a modified digital camera for documenting art works in the NIR with an example of revealing underdrawings in a painting. Additional examples of conservation applications for paper and paintings include Arslanoglu et al. (2013) who used IRR to complement X-ray radiography of paintings in the investigation of working methods and materials, and Gavrilov et al. (2013) who compared NIR, SWIR, and thermographic imaging for paintings inspection to look at working methods, changes in composition, and structural defects. These references reflect the history and development of reflected IR imaging for paintings and paper conservation and represent only a few of the many studies available.

In addition to the wide use of reflected IR imaging for 2D items, a few published studies provide examples for reflected IR documentation of 3D objects. Moss (1954) reported imaging repairs on a luster jug, and Gibson (1978) referenced studies of metals, a wooden object, stained glass, pottery fragments, and painted elements of archaeological sites. Mansfield et al. (2002) and Warda et al. (2011) suggested applications beyond paintings and paper, but did not provide specific details. Falco (2009) included a single example, a set of Japanese armor, where the technique was used for material differentiation.

The current availability of modified consumer digital single-lens reflex (DSLR) cameras for reflected IR imaging provide the option of higher spatial resolution cameras in comparison to the specialized cameras with SWIR sensitivity that are more expensive and tend to have a low spatial resolution. Modified DSLR cameras provide a lower cost option for conservation labs to conduct IR imaging. Additionally, these systems provide resulting 2D images with a high resolution and more potential to record small details. However, 2D imaging techniques, both visible and IR, provide only a limited representation of 3D objects.

1.2 THREE-DIMENSIONAL IMAGING

Three-dimensional imaging is used for cultural heritage documentation to record the surface geometry and in some cases texture of an object producing virtual and physical 3D models. Three-dimensional imaging allows digitization to extend beyond the limitations of 2D object documentation to monitor dimensional change, virtually reconstruct an object, reduce handling and grant access, create custom mounts or repairs, and produce replicas (Hess 2015). Techniques include range-based techniques like laser and white light scanning and image-based techniques like photogrammetry (see Remondino 2011c). Other 3D imaging techniques such as computed tomography (CT) scanning and micro-CT scanning use X-rays to record the shape and volume of an object, and 3D digital microscopy records geometry at the micro scale. Reviews of 3D imaging techniques for cultural heritage applications include Wachowiak and Karas (2009), Engel (2011), and Remondino (2011a, b, c). A variety of 3D imaging techniques have been used for conservation applications, for example, white light scanning to create a physical copy and virtually recreating a missing piece (Wachowiak et al. 2009); laser scanning for virtual reconstruction and custom support production (Arbace et al. 2013); and laser scanning for monitoring internal movement (Garland et al. 2015) and dimensional stability (Hess et al. 2015). These are only a few of many publications on 3D imaging for cultural heritage.

The present study focused on assessing two 3D imaging techniques that have been used for conservation applications: white light scanning as a more expensive and specialized option, and photogrammetry as a lower cost and more accessible technique using similar equipment to that used for reflected IR imaging. White light scanning is a range-based technique that involves the projection of light patterns onto an object and the recording of the pattern deformation to produce a 3D model of an object. It is a portable and accurate 3D imaging technique with good texture acquisition and useful for small-scale objects (Pratikakis et al. 2013). Photogrammetry is an image-based technique where surface geometry of an object can be estimated from at least two overlapping images. The term photogrammetry encompasses several techniques using different algorithms and calibration methods. Remondino et al. (2012) discusses how the photogrammetry community prioritized *accuracy* and *reliability* for applications in mapping, documentation and monitoring, while the computer vision community prioritized *automation* for applications in robotics and inspection (Remondino et al. 2012, 41). An example of an automated, image-based method developed by computer vision is Structure from Motion (SfM), a self-calibration approach that is widely used in cultural heritage documentation.

1.3 ASSESSING 3D IMAGING TECHNIQUES

As 3D imaging techniques are becoming more widely used in cultural heritage, many case studies and

comparative studies have been published. Engel (2011) described 3D technologies for natural history collections; Mathys et al. (2013a) compared five 3D imaging techniques; Koutsoudis et al. (2013) evaluated the performance of photogrammetry of a low-feature artifact compared to that of laser scanning; Mathys et al. (2013b) assessed low-cost techniques for field archaeology; and Abate et al. (2014) investigated 3D techniques for paintings. These publications provide examples of parameters that have been used to assess 3D imaging techniques including accuracy, shape discrepancies, and resolution. Andrews et al. (2015) defined accuracy as "the closeness between measurements and their true values. The closer a measurement is to its true value, the more accurate it is" (21). Shape discrepancies, or surface deviations, have been used to assess the accuracy of a technique compared to true values or to another 3D imaging technique (Koutsoudis et al. 2013; Mathys et al. 2013a) and to measure the difference between two aligned models.

Sampling resolution is used as a parameter for assessing quality and output of imaging techniques (Remondino et al. 2013). The resolution of range-based methods is defined by the specifications and performance of the device as provided by the manufacturer (Remondino et al. 2013). The resolution of image-based methods can be estimated as the ground sampling density (GSD) calculated from the object to camera distance, the focal length of the lens, and the pixel size of the camera (see Andrews et al. 2015). Understanding and evaluating the resolution for a technique requires knowing the size of the smallest feature that needs to be resolved for specific uses and the users. According to MacDonald (2010), the smallest feature size for most heritage materials would be in the range of 0.02–0.075 mm. The number of pixels (px) per mm, or the sampling rate, for digitization should be at least twice the value of the smallest feature (mm) that needs to be resolved (MacDonald 2010). Resolving features in the range of 0.02–0.075 mm would require a sampling rate of 27–100 px/mm for digitization. MacDonald (2010) suggested a standard digitization resolution of 50 px/mm to ensure that the details of 0.04 mm are resolved.

1.4 EXPERIMENTAL DESIGN

Reflected IR imaging, photogrammetry, and white light scanning were used to document six objects (fig. 1): two Egyptian painted wood figures and a Greek ceramic vessel from the Freud Museum in London, and two wood qeros and a ceramic vessel from the Smithsonian National Museum of the American Indian (NMAI) in Washington, DC. The present study provides examples of reflected IR imaging for enhanced detection of features of 3D cultural heritage objects; discusses the potential of integrating reflected IR and 3D imaging to more fully document features of 3D objects; and investigates two 3D imaging techniques, white light scanning and photogrammetry. The main objective is to compare the two techniques, one more expensive and the other more accessible, to discover whether there is a significant difference in performance for the purpose of resolving the details recorded by reflected IR imaging.

In the current study, reflected IR imaging was conducted with a modified DSLR camera. A similar setup for photogrammetry was used to maintain consistency for comparison between IR and visible in addition to the consideration of future research acquiring integrated data. A high performance lens was used for sharp results and to minimize focus shift between visible and IR (Warda et al. 2011, 138). The Peca 906 longpass filter, comparable to the Kodak Wratten 87A filter, was selected as it cuts off shorter IR wavelengths and could maximize the transparency of some materials. A Breuckmann SmartSCAN, used in the present study, is often utilized for industrial inspection, quality control, and reverse engineering, which all require high accuracy and precision. These systems also tend to be user friendly with a simple calibration process and accurate color capture. The SfM method of photogrammetry was selected for the present study as an inexpensive, portable, and accessible 3D imaging technique (Abate et al. 2014; Nicolae et al. 2014). The method is based on standard camera equipment, and some of the software solutions are available as freeware or are more affordable than some proprietary 3D scanning or analytical software.

2. CASE STUDIES

2.1 FREUD MUSEUM (LONDON, UK)

The Freud Museum (Maresfield Gardens, London, UK) is located in the family home of psychoanalyst Sigmund Freud where he lived the last year of his life. His daughter, Anna Freud, continued to live in the family home until her death in the 1980s when the house was converted to a museum. The museum now maintains and exhibits Freud's libraries, archives, and his collection of nearly 2000 Egyptian, Roman, Greek, and Oriental antiquities. Acquisition in February and March 2015 included twenty collection objects imaged with visible light imaging, reflected IR imaging, photogrammetry, and white light scanning. Three objects, the *Falcon-Headed Figure* (LDFRD 3124), the *Human Headed Ba-Bird* (LDFRD 3286), and the *Lekythos* (LDFRD 3702), are discussed in this paper.

The *Falcon-Headed Figure* (fig. 1a) is considered to be a 19th-century forgery of an Egyptian antiquity (FM Collections Catalog). The figure, a human body

FIG. 1   Six objects used as case studies from the Freud Museum (top row) and NMAI (bottom row): (a) *Falcon-Headed Figure*, 27 × 6 cm (LDFRD 3124); (b) *Human Headed Ba-Bird*, 14 × 6×12 cm (LDFRD 3286); (c) *Lekythos*, 23 × 9 cm (LDFRD 3702); (d) *Colonial Inka Qero*, 18 × 14 cm (NMAI 16/3605); (e) *Colonial Inka Qero* (*Jaguar head*), 23 × 15 cm (NMAI 10/5860); and (f) *Vessel*, 13 × 13 cm (NMAI 23/9575).

with a head shaped like a bird, was carved from wood and decorated with gesso and paint. It is thought to be a representation of Horus, the god of the sky and protector of the pharaoh (Gamwell and Wells 1989, 58 cited in FM Collections Catalog).

The *Human Headed Ba-Bird* (fig. 1b) is from the Egyptian Ptolemaic Period (332–30 BC) (FM Collections Catalog). The object, a bird body with a human head, was carved from wood and decorated with gesso and paint. It is thought to have been a part of a rounded wooden funeral stele and representative of the "ba", which along with the body and the life force were the three elements that a person was divided into at death (Gamwell and Wells 1989, 72 cited in

FM Collections Catalog). The "ba" can take the form of a bird to return to the land of the living.

The *Lekythos* (fig. 1c) is from fifth century BC Greece (FM Collections Catalog). The catalog lists the object as a "black figure" vessel depicting two warriors walking beside their horses. The *Lekythos* was reconstructed from many pieces, and parts of the decorations, warriors, horses, and the design, have been obscured by the reconstruction materials, fading, and wear.

2.2 SMITHSONIAN NATIONAL MUSEUM OF THE AMERICAN INDIAN (WASHINGTON, DC)

The Smithsonian National Museum of the American Indian (NMAI) holds one of the world's largest

collections of Native artifacts from the Western Hemisphere. Founded by George Gustav Heye, the Museum of the American Indian/Heye Foundation acquired the majority of the items in the collection from 1903 to 1957 with objects of "artistic, historic, literary, and scientific interest" that were to become the collections for "a museum for the collection, preservation, study, and exhibition of all things connected with the anthropology of the aboriginal people" of the Western Hemisphere as stated in the 1916 trust agreement (NMAI Website). Three collection objects were examined for this study in June 2015 with visible light imaging, reflected IR imaging, and photogrammetry, *Inka Qero* (NMAI 16/3605), *Inka Qero* (*Jaguar head*) (NMAI 10/5860), and *Vessel* (NMAI 23/9575).

The *Inka Qero* is an Andean qero, or ceremonial drinking vessel, manufactured 1550–1800 most likely in the Cusco region of Peru (fig. 1d) (NMAI Collections database record for 16/3605, accessed August 2, 2015). The NMAI collection of qeros has been investigated for the identification of materials and manufacture techniques in a long-term technical study (Kaplan et al. 2012; Newman et al. 2015). The form of this wooden vessel is typical for most qeros: an hourglass profile with the rim larger than base. This vessel is decorated in typical Colonial Inka style: incised lines and carved recessed motifs inlaid with pigmented resin to create figures and designs. There are depictions of a male and a female human figure on opposing sides of the vessel, two feline heads with rainbows springing from two feline heads, and design elements of flora, fauna, and geometric patterns. Craquelure patterns typical of this resin are observed in the polychromed areas; the incising and carving features are more visible in areas of loss.

The *Inka Qero* (*Jaguar head*) is an Andean ceremonial drinking vessel manufactured circa 1700 most likely in the highlands of Peru (fig. 1e) (NMAI Collections database record for 10/5860, accessed August 2, 2015). This wooden vessel in the shape of a jaguar head is an unusual but not unique form and the decoration, again, is atypical. This vessel includes pelage-patterned spots for the jaguar's fur, silver disks for the eyes, a ferrous metal band around the neck, and brass serpents as whiskers. Some of the spots in the pelage patterns do not contain any coloration, which may indicate surface loss.

The *Vessel* is listed in the catalog as an "incised clay cylindrical bowl with a flat bottom" from Mexico and described as a "Yucatan bowl" with an unknown manufacture date (fig. 1f) (NMAI Collections database record for 23/9575, accessed August 2, 2015). This type of object, known as a Maya cylinder vessel, is typically made of ceramic. However, NMAI Curator Dr. Antonio Curet and NMAI Conservator Emily Kaplan

(pers. comm.) noted that it is of suspicious authenticity due to its appearance under ultraviolet-induced fluorescence and its extraordinarily light weight suggesting it is made of plaster. Imaging was carried out to try to determine whether any part of the vessel was actually original ceramic. Cracks throughout the object are visible and suggest a past treatment to restore the vessel from a number of fragments, perhaps as part of the process of creating a fake.

3. METHODS

3.1 IMAGING TECHNIQUES

Reflected IR imaging was performed using a modified Canon 5D Mark II with a Coastal Optics 60 mm macro UV-VIS-IR APO lens. Modifications included the removal of the IR-cut filter and the color filter array with the result that it is sensitive to IR radiation up to about 1000 nm and acquires only monochrome images. A longpass Peca 906 filter on the lens was used to restrict the recorded radiation to the NIR region, cutting off wavelengths below about 950 nm. The objects were illuminated with two Lowel ViP Prolights with tungsten halogen lamps.

Photogrammetry was performed using a Canon 5D Mark II camera with a Coastal Optics 60 mm UV-VIS-IR APO macro lens. The objects were illuminated with the same lights as described above. The camera was mounted on a tripod with the object centered on a manual turntable. The turntable allowed for the object to be rotated while maintaining a constant working distance from camera to object. The image sets included multiple positions made up of views documenting a full rotation of the object. Agisoft Photoscan Pro software was used for processing the images into 3D models using a workflow provided by Cultural Heritage Imaging and the US Bureau of Land Management.

White light scanning was performed using the Breuckmann SmartSCAN with two 5-megapixel cameras, 300 mm lenses, and an automated Breuckmann turntable. The data were acquired and processed using the proprietary Breuckmann 3D software, OptoCAT 2014. The white light scanning was conducted in the Freud Museum during open hours, so control over the ambient light was not possible and texture information was not acquired. A 3D scanner was not available for the NMAI case study.

4. RESULTS

4.1 REFLECTED IR IMAGING

The results of the reflected IR imaging of the three objects from the Freud Museum are illustrated with visible light images and reflected IR image details in

figure 2. The IR images of the *Falcon-headed Figure* showed the contrast in reflection, transmission, and absorption between the brown-pigmented areas of the skin and clothing, which appeared lighter due to the transmission of IR radiation and the reflection from the gesso, and the lines, which appeared darker due to the higher IR absorption. Areas where IR radiation was absorbed appeared dark including linear designs and outlines of the face, eye, and details of the beak (fig. 2a); the outlines around the hip (fig. 2b); and the repetitive lines on the neck and chest (fig. 2c). The IR images of the *Human Headed Ba-Bird* showed the reflection, transmission, and absorption of the pigments used to decorate this object. The visibility of a crack on the proper left foot, an area of red pigment that is transparent with IR radiation, was increased in the IR image (fig. 2d). The contrast between the transparent green pigment on the head, wings, and base and the absorption of IR radiation revealed the fine details of cracks (figs. 2e, 2f). The IR imaging of the *Lekythos* showed the material used for past restoration as transparent and the underlying design absorbed the IR radiation (fig. 2g). The material used to depict the figures on the body of the vessel still absorbed IR radiation despite apparent fading or obstruction in the visible light image (fig. 2h). The smallest features estimated on the three objects were painted lines greater than 0.3 mm and cracks smaller than 0.1 mm (table 1). Feature measurements were estimated from still images calibrated using a measurement scale included in the image.

The results of the reflected IR imaging of the three NMAI objects are illustrated with visible light images and reflected IR image details in figure 3. The IR images of the *Inka Qero* showed the incised outlines of the figures and design elements with some of these fine lines extending into neighboring elements as seen in figure 3a (circles). The eye and hair, which are black in the visible light image, either disappeared in the IR image (the eye) or became a light gray (the hair) indicating little to no absorption of the IR radiation (fig. 3b, arrow). An increased contrast of the fine lines that absorbed IR radiation enhanced the visibility of the craquelure (fig. 3b, circle). The IR images of the *Inka Qero* (*Jaguar head*) showed the spots with missing materials as reflective and similar in tone to the brown pigment (fig. 3d, circle). The enhanced contrast of the IR images emphasized cracks in the brown areas especially toward the rim of the vessel (fig. 3e), but fine cracks were not observed in the dark spots. The IR images indicated that two materials may have been used for some of the pelage-patterned spots. Parts of the spots became transparent, while a second material absorbed the IR radiation and remained dark (fig. 3f) resulting in an appearance of uneven application. The IR images of the *Vessel* showed an increase in the visibility of overpainted fills and repairs on both the interior (fig. 3g) and the exterior (figs. 3h, 3i) of the
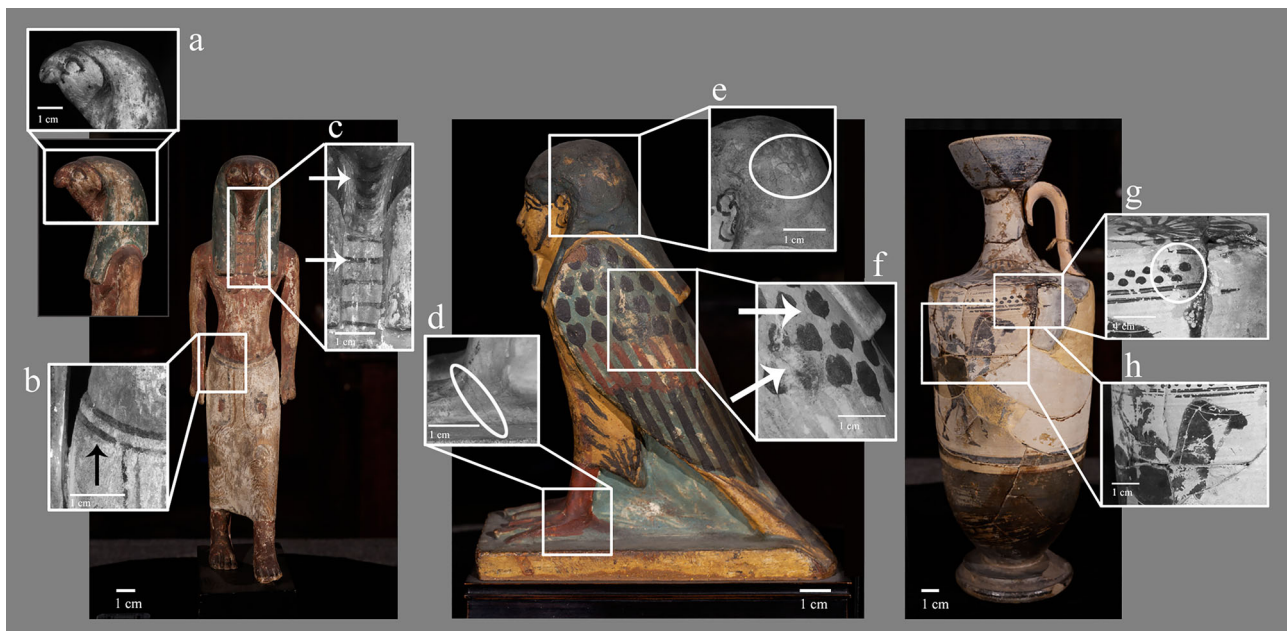

FIG. 2   Visible light images and reflected IR details of the Freud Museum objects. *Falcon-Headed Figure* (left): (a) IR detail of lines around the face, eyes, and beak; (b) IR detail of lines depicting clothing around the hip (arrow); and (c) IR detail of the repetitive lines on the neck and chest (arrows). *Human Headed Ba-Bird* (center): (d) IR detail of a crack across the proper left foot of object (ellipse); (e) IR detail of the cracks in the head of the figure (circle); and (f) IR detail of the cracks in the proper left wing (arrows). *Lekythos* (right): (g) IR detail of the design with IR radiation penetrating repair materials (circle) and (h) IR detail of a figure on the body of the vessel absorbing IR radiation.

TABLE 1 RESOLUTION AND RESULTING DETAILS

	Resolution of still images (px/mm)	Smallest features (mm)
Falcon-Headed Figure	20	Painted lines >0.9
Human Headed Ba-Bird	28	Painted lines >0.3; Cracks <0.1
Lekythos	20	Painted lines >0.5; Cracks <0.3
Inka Qero	19	Incised lines 0.2; Cracks <0.1; Design elements >0.4
Inka Qero (Jaguar)	13	Cracks >0.2; Design elements >1
Vessel	24	Incised lines 0.4–1; Cracks >0.1

object. The difference in reflection and absorption on the face of one of the figures suggested a different material was used for the repair (fig. 3i). The smallest features estimated on the three objects included incised lines 0.3–0.6 m, cracks about 0.1 mm, and design elements larger than 0.4 mm (table 1).

4.2 THREE-DIMENSIONAL IMAGING

The 3D imaging of the three objects from the Freud Museum resulted in textured photogrammetric models (fig. 4, left column) and non-textured white light scanned models (fig. 4, right column). The photogrammetry of the *Falcon-Headed Figure* produced a model with excess data under the arms (fig. 4a), a challenging area to document with both photogrammetry and white light scanning. The resulting white light scanned model had holes in the data for this area (fig. 4b). The photogrammetry of the *Human Headed* *Ba-Bird* produced a model with areas that resolved fine details of the coarse surface, while other details were blurred (fig. 4c). Areas of the model had uneven rough surfaces not representative of the object's actual surface especially between the legs and feet (fig. 4d). The white light scanned model appearing to have a smoother surface more accurately represents the object, including some pits and bumps (fig. 4e). However, this model had missing data, seen as holes, around the feet, legs, and base (fig. 4f). The photogrammetry of the *Lekythos* produced a model that resolved the surface geometry of a crack approximately 0.6 mm (fig. 4g) and additional crack details seen in figure 4h. The white light scanned data resulted in a model that resolved the same crack as figure 4g with increased clarity (fig. 4i), and a smooth surface appearing to be more truthful to the actual surface. However, this model also had missing data, seen as holes around the base (fig. 4j).
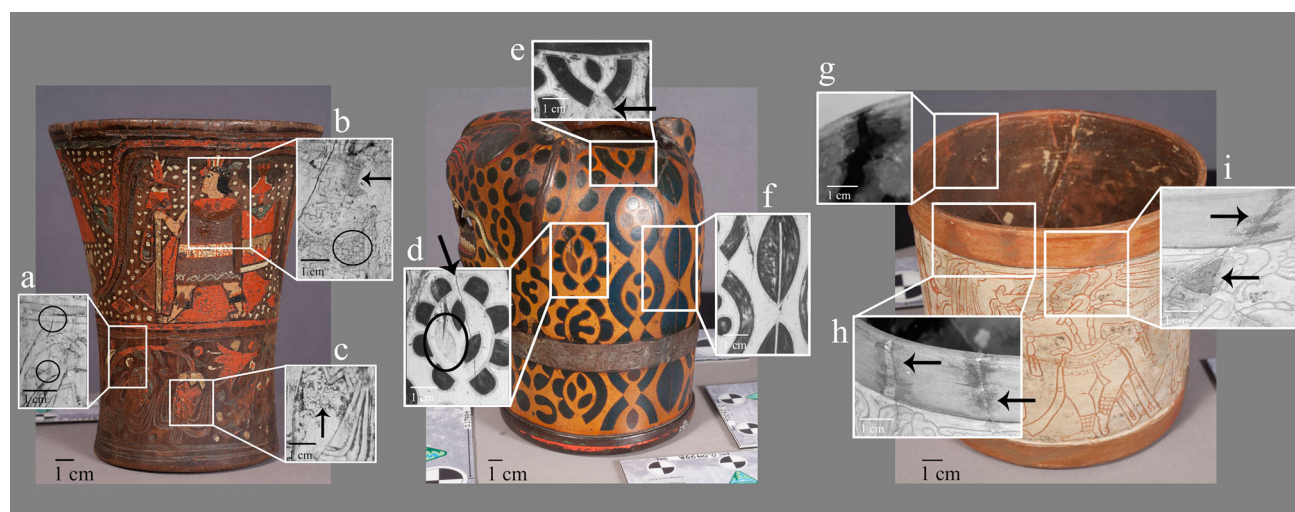

FIG. 3   Visible light images and reflected IR details of the NMAI objects. *Inka Qero* (left): (a) IR detail of the incised lines (circles); (b) IR detail of the hair of the male figure (arrow) and the craquelure pattern of the pigmented resin (circle); and (c) IR detail of the craquelure and loss of inlaid material (arrow). *Inka Qero (Jaguar head)* (center): (d) IR detail of pelage-patterned spots with area of missing material (circle) and the fine crack (arrow); (e) IR detail of the craquelure at the rim of the object (arrow); and (f) IR detail of the uneven dark spots. *Vessel* (right): (g) IR detail of material that absorbed IR significantly more than surrounding material; (h) IR detail of past repairs and fills (arrows); and (i) IR detail of overpainted crack and different material used for face of figure (arrows).
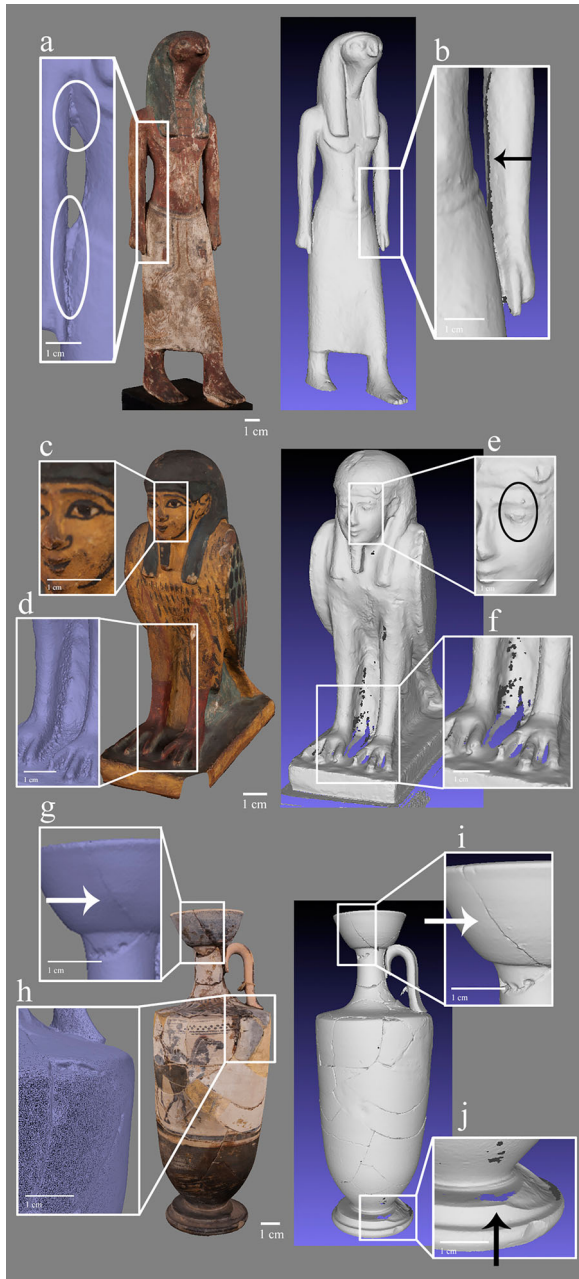
FIG. 4   Textured view of photogrammetry models (left column) and white light scanned models (right column) of Freud Museum objects. *Falcon-Headed Figure* (top): (a) solid view detail of excess data under the arm of the figure (circles) and (b) detail view of missing data under the arm of the figure (arrow). *Human Headed Ba-Bird* (middle): (c) textured view of varying resolution of facial details (eye is blurred and cheek resolved sand-like detail); (d) solid view of photogrammetry model and the uneven, rough surface between legs and feet; (e) detail of pits and bumps on the face and a smooth surface roughness; and (f) detail view of areas of missing data. *Lekythos* (bottom): (g) solid view resolving detail of crack; (h) wireframe view of missing piece and cracks; (i) detail view of same crack as (g); and (j) detail view of base with areas of missing data.

5. ANALYSIS

5.1 REFLECTED IR IMAGING OF 3D CULTURAL HERITAGE OBJECTS

The imaging case studies at the Freud Museum and NMAI have provided examples of using reflected IR imaging for enhanced detail detection of 3D cultural heritage objects. The IR images of the *Falcon-Headed Figure* and the *Lekythos* enhanced the visibility of design elements that had been obscured by reconstruction materials, fading, and wear. The IR images of the *Human Headed Ba-Bird* revealed cracks throughout the object (head, wings, and foot). The identification of these cracks can contribute to the understanding of the condition of the object.

The reflected IR images of the two NMAI qeros build on the long-term technical study (Kaplan et al. 2012; Newman et al. 2015) that provided information about the materials and manufacture. The lack of IR absorption of the hair and eye of the male figure on the *Inka Qero* suggested that the pigment is not carbon based as originally thought. The IR images of the *Inka Qero* showed the incised lines and inlaid resin proposed by Kaplan et al. (2012) as traditional qero manufacture techniques. In contrast to the craquelure pattern of the pigmented resin of the *Inka Qero*, the *Inka Qero* (*Jaguar head*) lacked craquelure in the pelage-patterned spots. The IR images of *Inka Qero* (*Jaguar head*) provided no evidence of incised lines, and the loss of material in the spots did not correspond to the craquelure and losses observed in the images of the *Inka Qero*. Comparison of the IR images for the two qeros suggests that the *Inka Qero* (*Jaguar head*) was not polychromed with the same methods and materials used for the *Inka Qero*; this is currently under investigation at NMAI.

The smallest features estimated from the reflected IR images included incised lines approximately 0.3–0.6 mm, cracks smaller than 0.1 mm, and design elements larger than 0.3 mm. While smaller details could be documented by acquiring detail images with a standard camera or using microscopy, the presented results provide a general idea of some feature sizes that can be recorded when the entire object is in the field of view. Using a modified DSLR camera with the same resolution as the camera used for visible light documentation provided a high-resolution option for reflected IR imaging allowing for small features to be recorded.

5.2 COMPARING PHOTOGRAMMETRY TO WHITE LIGHT SCANNING

In order to assess photogrammetry and white light scanning, evaluation parameters were selected based
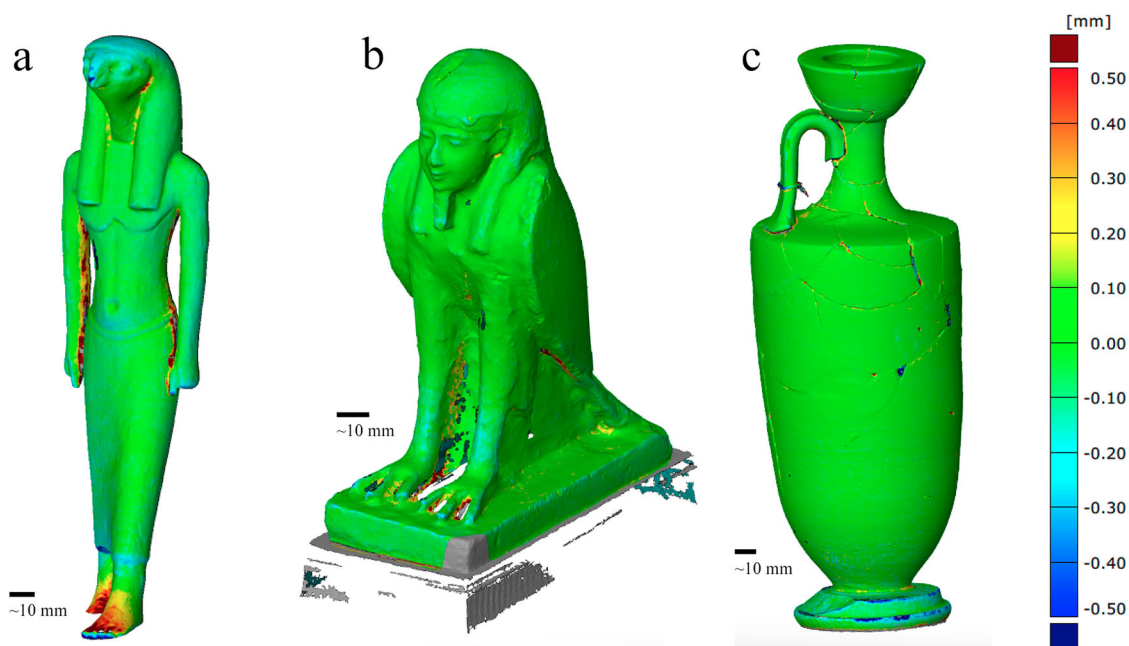
FIG. 5   Deviation maps illustrating the shape difference, or surface deviation, of the photogrammetric models compared to the white light scanned models. The deviation maps were created using GOM Inspect software: (a) *Falcon-Headed Figure*; (b) *Human Headed Ba-Bird*; and (c) *Lekythos*.

on a review of current publications in the field as discussed in Section 1.3. These parameters include accuracy, shape discrepancies, and resolution. True values, or a "ground truth", were not available for the objects in the present study and, therefore, we were not able to evaluate accuracy of the models. Instead white light scanning results were used as the reference data for evaluating photogrammetry models, similar to the study by Koutsoudis et al. (2013) comparing photogrammetry models to laser scanning models.

Shape discrepancies between the photogrammetry models and the white light scanned data were visualized with deviation maps, false-color images indicating positive (yellow, orange, and red) and negative (turquoise and blue) shape differences (fig. 5). For example, the largest discrepancies in the *Falcon-Headed Figure* models were in the areas of the feet, beak, underarms, and hairline (fig. 5a). The feet and beak areas were slightly out of focus in many of the photogrammetry images, which could be improved by additional camera positions and increased depth of field. The areas under the arms and around the hairline were difficult to image as there was a loss of information from self-shadowing and the features presented fewer overlapping camera views. Similarly, the largest discrepancies in the *Human Headed Ba-Bird* models were in the areas between the legs and feet (fig. 5b). This area was not fully documented by white light scanning, and, therefore, the deviation maps show a difference between the photogrammetry and white light scanned

model. In addition, the *Lekythos* model had discrepancies around its base and the crack details (fig. 5c) because the base and the depth of the cracks were not fully documented by white light scanning. The surface deviation map was green over most of the three objects indicating that the 3D models from photogrammetry and white light scanning are similar and a majority of the compared geometries are within ± 0.1 mm of each other.

Resolution (x, y) advertised by the manufacturer for the white light scanner was 0.1 mm for the 300 mm optics (Breuckmann SmartSCAN), which is not enough to resolve fine cracks that can be less than 0.02 mm (MacDonald 2010). Only the input images for the *Human Headed Ba-Bird* were in the suggested sampling resolution range (27–100 px/mm) to resolve the 0.02–0.075 mm features presented by MacDonald (2010). If most input images cannot resolve the features, then the resulting photogrammetry models will not resolve them either. The sampling resolution suggested by MacDonald (2010) may be more than what is needed, but the resolution needed is dependent on the object imaged and project objectives. The surface geometry of the photogrammetry models for this study was able to resolve cracks larger than 0.2 mm and incised lines averaging 1 mm, but not the finest crack details (<0.1 mm). The photogrammetry texture was able to resolve some of the fine crack details and other features of interest including larger cracks, incised lines (>0.2 mm), and painted design elements

(>0.4 mm). The features are presented as x, y measurements and the z dimensions and depth resolution are not addressed in this study.

6. DISCUSSION

The reflected IR imaging of the six objects enhanced the visibility of design elements in the *Falcon-Headed Figure* and the *Lekythos*, revealed cracks in the *Human Headed Ba-Bird*, and provided information about materials and manufacture for the *Inka Qero* and the *Inka Qero* (*Jaguar head*). The comparison of the resulting IR images for the two qeros suggested different materials and manufacture methods, which is continuing to be investigated. The reflected IR results from the documentation of these objects supports the use of the technique for 3D objects to increase the visibility of obscured details, reveal surface features, and provide additional information about materials and manufacture.

Challenges for this study included presenting the results for visible light and reflected IR imaging, which required representing 3D objects with 2D images. The IR image details of the objects are shown side-by-side in reference to visible light images. However, these are selected 2D views of the object, which do not fully represent the entire object. Three-dimensional imaging has potential to work beyond the limitations of 2D images in acquiring the full dimensionality of a 3D object by recording the surface geometry and texture of an object. Integrating reflected IR with 3D imaging would allow the features recorded by reflected IR imaging to be more accurately mapped and provide insight about materials, manufacture, and condition. If reflected IR and 3D imaging can be integrated, the question then arises whether accessible 3D techniques can produce a model with sufficient resolution to document the details recorded with reflected IR imaging.

This research compared two 3D imaging techniques to discover whether there is a significant difference in the performance between these techniques and whether the techniques can resolve the features recorded in reflected IR imaging. Techniques like micro-CT scanning and 3D digital microscopy may provide high-resolution 3D geometric data at the micro scale. However, white light scanning was selected as a more expensive and specialized technique and photogrammetry as the less expensive technique using similar equipment to that of reflected IR imaging. The surface deviation maps comparing the models from white light scanning and photogrammetry show a close similarity mostly within ±0.1 mm of each other.

The resulting models were not able to resolve some of the smallest features; however, the resolution can be increased for both techniques. For white light scanning the resolution can be increased by reducing the field of view with the scanning optics. Several components can improve the resulting 3D data from photogrammetry. Reducing the working distance, changing the optics, and increasing the camera resolution can all increase the resulting resolution (Koutsoudis et al. 2013). Lighting is also very important; even, diffuse illumination and reducing the effect of shadows will improve the resulting data (Koutsoudis et al. 2013). Defining the documentation objectives and the finest features that need to be recorded can be used to estimate the best GSD for the project and to determine the distance needed between the object and camera or possibly the best lens or camera. For the current study, the GSD was not calculated for each object; instead a setup was used for a group of objects irrespective of the object and finest features. Additionally, calibrated scale bars can improve accurate measurement. Including coded targets in the imaging scene can improve accuracy (Sapirstein 2016). However, coded targets cannot be used in many applications for cultural heritage documentation if placed directly on the object because of the risk to the surface. An option could be to place coded targets around an object. Additionally, instead of coded targets, repeatability tests as discussed in Sapirstein (2016) and presented in Dellepiane et al. (2013) could be an option to better understand the accuracy and reliability of the resulting data as acquired in specific settings.

Researchers have presented photogrammetry as an accessible, portable, and flexible technique that can provide high-resolution results to a non-expert user for cultural heritage documentation (Abate et al. 2014; Nicolae et al. 2014). The camera equipment needed for SfM is not specialized and can be found in many conservation labs. The software can be freely available or purchased at a low cost and some options are user friendly, making the technique accessible for cultural heritage documentation. The equipment used for this study included a tripod and fit into an airplane carry-on size rolling case that can be transported easily. The scalability of photogrammetry is also an advantage. It can document a range of materials and object sizes without additional equipment costs. Additionally, acquired images for photogrammetry can be reprocessed as the technology and algorithms continue to develop and improve. These are all advantages for photogrammetry that are considered when selecting the technique for cultural heritage documentation over other 3D imaging techniques.

SfM methods have been questioned by Remondino et al. (2012), Green et al. (2014), and Sapirstein (2016). Remondino et al. (2012, 42) stated that SfM 3D reconstructions should be used for visualization and not for photogrammetric or mapping purposes. Green et al. (2014, 181) concluded SfM is "a less

accurate, but cheaper and higher resolution substitute" for some of the more expensive higher-end laser scanning techniques. SfM is widely used for cultural heritage documentation, but the question arises whether the method is providing reliable results that heritage professionals expect with a model that "looks good". Sapirstein (2016) reiterated Green et al. (2014) and the need to assess the accuracy of photogrammetry reconstructions if used for measurements. Some of the photogrammetry reconstructions presented in the current study were compared to white light scanned data providing a relative idea about the reliability of the resulting geometry. However, the white light scanned data does not provide a ground truth and many 3D imaging campaigns will not and cannot include two techniques to document each object and assess the accuracy of the photogrammetric reconstructions.

There is still a need for established best practices for documentation of 3D cultural heritage objects and assessing the accuracy of the resulting 3D models. While 3D imaging techniques can be accessible to the non-expert user, especially SfM, specialist knowledge and the experienced user can improve the accuracy and reliability of the resulting data. If a 3D model is to be used for measurements and more than visualization, it is important to have an understanding of the accuracy and reliability of the technique and resulting data. Having a model that "looks good" does not mean that it can be used for metric applications. Hess (2015) notes that 3D data of museum and archaeological objects can be highly inconsistent including variation in geometric accuracy, resolution, and color (31) and that skills of the operator can impact the 3D imaging results (182). Working toward best practices, Andrews et al. (2015) provide metric survey specifications for mostly monuments and built heritage, and Hess (2015) presents the creation of a prototype portable 3D test standard specifically for heritage applications that will allow comparison of geometry, color, and spatial resolutions among 3D imaging systems. As 3D imaging continues to be widely used, an awareness is needed that considers the intended use of the 3D models and whether the technique and resulting data can support that use.

7. Conclusions

Reflected IR imaging allows the enhanced detection of details, which is known from its established uses as an investigation tool in conservation for 2D and 3D objects. The resulting documentation of the objects from the Freud Museum and NMAI support the utility of reflected IR imaging of 3D objects for enhanced detection of details: increasing visibility of obscured details, revealing surface features that indicate

the condition, and providing information about materials and manufacture.

The resulting 2D IR images do not fully represent the 3D object. The integration of reflected IR and 3D imaging could provide an effective way to visualize and map the resulting IR imagery and to increase accuracy of the spatial location of the details. The present study assessed white light scanning and photogrammetry to investigate whether an accessible 3D imaging technique could resolve similar detail to reflected IR imaging. The key conclusion of the comparison is that the resulting models are similar and neither was able to resolve some of the smallest features recorded by reflected IR imaging. However, the resolution for both techniques can be increased. Defining the objectives of imaging to plan the setup and acquisition ensure that the appropriate resolution is used to document the objects.

The advantages of cost, portability, flexibility, and accessibility of photogrammetry present a promising option for the integration of IR and 3D. Given the examples of reflected IR imaging for enhanced detection of details and photogrammetry or white light scanning to resolve fine details, the integration of reflected IR and 3D imaging could provide a multi-layered view and an enhanced understanding of an object.

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REFERENCES

Abate, D., F. Menna, F. Remondino, and M. G. Gattari. 2014. 3D painting documentation: Evaluation of conservation conditions with 3D imaging and ranging techniques. *ISPRS Technical Commission V Symposium*. Riva del Garda, Italy.

Andrews, D., J. Bedford, and P. Bryan. 2015. *Metric survey specifications for cultural heritage*. Swindon: Historic England.

Arbace, L., E. Sonnino, M. Callieri, M. Dellepiane, M. Fabbri, A. I. Idelson, and R. Scopigno. 2013. Innovative uses of 3D digital technologies to assist the restoration of a fragmented terracotta statue. *Journal of Cultural Heritage* 14 (4): 332–45.

Arslanoglu, J., S. Centeno, S. Digney-Peer, and I. Duvernois. 2013. 'Picasso in the Metropolitan Museum of Art': An investigation of materials and techniques. *Journal of the American Institute for Conservation* 52(3): 140–55.

Breuckmann SmartSCAN White Light 3D Scanner. Accurex, Swarthmore, PA. www.accurexmeasure.com/smartscan. htm (accessed 06/26/15).

Dellepiane, M., N. Dell'Unto, M. Callieri, S. Lindgren, and R. Scopigno. 2013. Archaeological excavation monitoring using dense stereo matching techniques. *Journal of Cultural Heritage* 14(3): 201–10.

Engel, J. 2011. 3D applications in museological context. Master's thesis, The Royal Danish Academy of Fine Arts, København, Denmark.

Falco, C. M. 2009. High resolution digital camera for infrared reflectography. *Review of Scientific Instruments* 80(7): 071301. doi:10.1063/1.3174431.

Fischer, C., and I. Kakoulli. 2006. Multispectral and hyperspectral imaging technologies in conservation: Current research and potential applications. *Studies in Conservation* 51(1): 3–16.

Freud Museum (FM) Collections Catalog. http://www.freud. org/uk/about/collections/ (accessed 05/08/2015).

Gamwell, L., and R. Wells, ed. 1989. *Sigmund Freud and art: His personal collection of antiquities*. Binghamton, NY: State University of New York; London: Freud Museum.

Garland, K. M., J. Bernstein, and J. Rogers. 2015. Raising Meret-It-Es: Examining and conserving an Egyptian anthropoid coffin from 380–250 BCE. *Journal of the American Institute for Conservation* 54(2): 102–13.

Gavrilov, D., E. Maeva, O. Grube, I. Vodyanoy, and R. Maev. 2013. Experimental comparative study of the applicability of infrared techniques for non-destructive evaluation of paintings. *Journal of the American Institute for Conservation* 52: 48–60.

Gibson, H. L. 1978. *Photography by infrared: Its principles and applications*. New York: John Wiley & Sons.

Green, S., A. Bevan, and M. Shapland. 2014. A comparative assessment of structure from motion methods for archaeological research. *Journal of Archaeological Science* 46 (1): 173–81.

Hess, M. 2015. A metric test object informed by user requirements for better 3D recording of cultural heritage artefacts. PhD thesis, University College London.

Hess, M., C. Korenberg, C. Ward, S. Robson, and C. Entwistle. 2015. Use of 3D laser scanning for monitoring the dimensional stability of a byzantine ivory panel. *Studies in Conservation* 60(Suppl. 1): S126–33.

Kaplan, E., E. Howe, E. Pearlstein, and J. Levinson. 2012. The qero project: Conservation and science collaboration over time. The American Institute for Conservation of Historic and Artistic Works (AIC) 40th Annual Meeting: Research and Technical Studies Specialty Group Postprints, 8–12 May 2012, Albuquerque, New Mexico. Washington, DC: AIC.

Keck, S. 1941. A use of infra-red photography in the study of technique. *Technical Studies in the Field of the Fine Arts* 9 (3): 145–52.

Koutsoudis, A., B. Vidmar, and E. Arnaoutoglou. 2013. Performance evaluation of a multi-image 3D reconstruction software on a low-feature artefact. *Journal of Archaeological Science* 40: 4450–6.

MacDonald, L. 2010. The limits of resolution. In *EVA London 2010: Electronic Visualisation & the Arts. Proceedings of a conference held in London 6-8 July*. ed. A. Seal with J. Bowen and K. Ng. London: BCS. 149–56.

Mairinger, F. 2004. UV-, IR- and X-ray-imaging. In *Non-destructive microanalysis of cultural heritage materials*. ed. K. H. A. Janssens, and R. Grieken. Antwerp: Wilson & Wilson Elsevier. 15–73.

Mansfield, J. R., M. Attas, C. Majzels, E. Cloutis, C. Collins, and H. H. Mantsch. 2002. Near infrared spectroscopic reflectance imaging: A new tool in art conservation. *Vibrational Spectroscopy* 28 (1): 59–66.

Mathys, A., J. Brecko, and P. Semal. 2013a. Comparing 3D digitizing technologies: What are the differences? In *Proceedings of Digital Heritage International Congress (Digital Heritage)*, Vol. 1. Marseille, France. New York: IEEE. 201–4.

Mathys, A., J. Brecko, K. Di Modica, G. Abrams, D. Bonjean, and P. Semal. 2013b. Agora 3D. Low cost 3D imaging: A first look for field archaeology. *Notae Praehistoricae* 33: 33–42.

Moss, A. 1954. *The application of x-rays, gamma rays, ultraviolet and infra-red rays to the study of antiquities*. London: Museum Association.

Newman, R., E. Kaplan, and M. Derrick. 2015. Mopa Mopa: Scientific analysis and history of an unusual South American resin used by the Inka and artisans in Pasto, Colombia. *Journal for the American Institute for Conservation* 54(3): 123–48.

Nicolae, C., E. Nocerino, F. Menna, and F. Remondino. 2014. Photogrammetry applied to problematic artefacts. In *ISPRS Technical Commission V Symposium*. Riva del Garda, Italy. 451–6.

NMAI Website. http://nmai.si.edu/explore/collections/ history/ (accessed 08/25/2015).

Pratikakis, I., A. Koutsoudis, and M. Savelonas. 2013. State of the art report on 3D object digitization and shape matching/retrieval methods for unstructured 3D data. Predictive digitization, restoration and degradation

assessment of cultural heritage objects (PRESIOUS). http://presious.eu (accessed 02/10/16).

Rawlins, F. I. G. 1938. A novel infra-red camera for art gallery work. *The Museums Journal* 38: 186–8.

Remondino, F. 2011a. Accurate and detailed image-based 3D documentation of large sites and complex objects. In *Digital imaging for cultural heritage preservation: Analysis, restoration, and reconstruction of ancient artworks*, ed. F. Stanco, S. Battiato, and G. Gallo. Boca Raton, FL: CRC Press. 127–57.

Remondino, F. 2011b. Heritage recording and 3D modeling with photogrammetry and 3D scanning. *Remote Sensing* 3: 1104–38.

Remondino, F. 2011c. Advanced 3D recording techniques for the digital documentation and conservation of heritage sites and objects. *Change Over Time* 1(2): 198–214. doi:10.1353/cot.2011.0012.

Remondino, F., S. Del Pizzo, T. P. Kersten, and S. Troisi. 2012. Low-cost and open-source solutions for automated image orientation – a critical overview. In *Progress in Cultural Heritage Preservation: 4th International Conference EuroMed 2012*, ed. M. Ioannides, D. Fritsch, J. Leissner, R. Davies, F. Remondino, and R. Caffo. Limassol, Cyprus: Springer. 40–54.

Remondino, F., F. Menna, A. Koutsoudis, C. Chamzas, and S. El-Hakim. 2013. Design and implement a reality-based 3D digitization and modeling project. *Proceedings of Digital Heritage International Congress (Digital Heritage)*, Vol. 1. Marseille, France. New York: IEEE. 137–44.

Sapirstein, P. 2016. Accurate measurement with photogrammetry at large sites. *Journal of Archaeological Science* 66: 137–45.

Van Asperen de Boer, J. R. J. 1969. Reflectography of paintings using an infrared Vidicon television system. *Studies in Conservation* 14(3): 96–118.

Wachowiak, M. J., and B. V. Karas. 2009. 3D scanning and replication for museum and cultural heritage applications. *Journal for the American Institute for Conservation* 48: 141–58.

Wachowiak, M. J., B. V. Karas, and R. E. Baltrusch. 2009. Reconstruction of a nineteenth century plaster piece mold and recreation of a casting. In *Making History Interactive. Computer Applications and Quantitative Methods in Archaeology (CAA 2009)*. ed. B. Frischer, J. Webb Crawford, and D. Koller. Williamsburg, VA: Archaeopress.

Warda, J. (ed.), F. Frey, D. Heller, D. Kushel, T. Vitale, and G. Weaver. 2011. *The AIC guide to digital photography and conservation documentation*. 2nd ed. Washington, DC: American Institute for Conservation of Historic and Artist Works.

Sources of Materials

Canon 5D Mark II, Lowel ViP Pro-Light
  B&H Photo Video
  420 9th Ave.
  New York, NY 10001, USA
  866-254-1492
  http://www.bhphotovideo.com

UV + IR + Visible Camera Modification
  MaxMax
  220 Broad St.
  Carlstadt, NJ 07072, USA
  201-882-0344
  http://maxmax.com

Coastal Optics UV-Vis-IR 60 mm APO Macro lens
  Jenoptik Optical Systems
  16490 Innovation Drive
  Jupiter, FL 33478, USA
  561-881-7400
  http://www.jenoptik-inc.com

Agisoft Photoscan
  Agisoft LLC
  11 Degtyarniy per.,
  St. Petersburg, Russia, 191144
  +7(812) 621-33-41
  http://www.agisoft.com/

Breuckmann SmartSCAN, Breuckmann turntable, OptoCAT 2014 software
  Breuckmann GmbH
  Torenstraße 14, 88709
  Meersburg, Germany
  http://aicon3d.com/

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Résumé - Les techniques d'imagerie contribuent à la conservation, à la recherche et à la compréhension des collections muséales. Lors de cette étude, deux techniques d'imagerie ont été examinées: l'imagerie infrarouge (IR) et tridimensionnelle (3D). La réflectographie infrarouge est bien établie comme outil d'examen en conservation-restauration, donnant de l'information sur l'état, les matériaux et la fabrication, au-delà de ce que peut donner l'examen sous lumière visible. La réflectographie infrarouge produit des images en 2D, lesquelles sont limitées pour représenter les objets 3D. Les techniques d'imagerie tridimensionnelle, comme la numérisation par balayage 3D et la photogrammétrie, étendent les possibilités de numérisation en enregistrant la géométrie et la

texture d'un objet. La réflectographie infrarouge, la numérisation 3D et la photogrammétrie ont été utilisées pour documenter six objets provenant du Musée Freud de Londres et du Musée national des Indiens d'Amérique au Smithsonian. La présente étude fournit des exemples de réflectographie IR permettant une détection améliorée des particularités des objets du patrimoine culturel. Elle examine aussi le potentiel d'intégration de la réflectographie IR à l'imagerie 3D afin de documenter plus complètement les surfaces des objets 3D. Enfin, elle compare deux techniques d'imagerie 3D: la numérisation par balayage 3D et la photogrammétrie. L'étude évalue les deux techniques d'imagerie 3D, l'une plus coûteuse et l'autre plus accessible, afin de déterminer si l'une des deux techniques est significativement plus performante pour accéder au niveau de détail enregistré par la réflectographie IR. Traduit par Isabelle Cloutier et Bruno Pouliot.

Resumo - As técnicas de imagem fornecem informações da conservação, pesquisa e compreensão das colecções dos museus. Dois tipos de técnicas de imagem foram examinados neste estudo: infravermelho (IV) e imagem tridimensional (3D). A imagem de infravermelho refletido está bem estabelecida como um instrumento de investigação, fornecendo informação sobre a condição, materiais e manufatura, além da documentação da luz visível. Imagem de infravermelho refletido resulta em imagens 2D, que são limitadas na maneira como representam objetos 3D. As técnicas de imagem tridimensional, como a digitalização com luz branca e fotogrametria, ampliam as possibilidades de digitalização pelo registo da geometria e da textura de um objecto. A imagem de infravermelho refletido, a fotogrametria, e a digitalização por luz branca foram usadas para documentar seis objetos do Museu Freud e do Museu Nacional Smithsonian do Índio Americano. O presente estudo fornece exemplos de imagem de IV refletido para aprimorar a detecção de características de objectos do patrimônio cultural em 3D; discute o potencial de integrar o IV refletido e a imagem 3D para documentar mais completamente as características de imagem de objetos 3D; e investiga duas técnicas de imagem 3D: digitalização por luz branca e fotogrametria. O estudo avalia as duas técnicas de imagem 3D, uma mais cara e outra mais acessível, para detectar se há uma diferença significativa no desempenho para a finalidade de resolver os detalhes gravados por imagem de IV refletido. Traduzido por Cristina Antunes.

Resúmen - Las técnicas de imagen informan sobre la conservación, la investigación y el entendimiento de las colecciones de museos. En este estudio se examinaron dos tipos de técnicas de imagen: infrarroja (IR) y tri-dimensional (3D). La imagen infrarroja reflejada es una herramienta de investigación bien establecida en conservación que ofrece información acerca de la condición, materiales y fabricación, que va más allá de la documentación que ofrece la luz visible. La imagen reflejada da como resultado imágenes 2D, las cuales tienen limitaciones para representar objetos 3D. Las técnicas de imagen tridimensionales, tales como el escaneo con luz blanca y la fotogrametría, extienden las posibilidades de la digitalización ya que registran la geometría y la textura de un objeto. Se utilizaron las técnicas de imágenes infrarrojas reflejadas, fotogrametría y escaneo con luz blanca para documentar seis objetos del Museo Freud y del Museo nacional Smithsonian del indígena americano. Este estudio ofrece ejemplos de imágenes reflejadas IR para la detección realzada de las características 3D de objetos de patrimonio cultural; discute el potencial de integrar las técnicas de imagen IR y 3D para documentar más ampliamente las características de los objetos 3D, e investigar dos técnicas de imagen 3D, escaneo con luz blanca y fotogrametría. El estudio evaluó las dos técnicas de imagen 3D, una más costosa y la otra más accesible, para descubrir si hay una diferencia significativa en su desempeño para fines de resolver los detalles registrados por imagen IR reflejada. Traductoras: Hilda Abreu de Utermolhen, y María Esteva. Revisión: Amparo Rueda.