Reflected Infrared Imaging

Revisiting the Fundamentals

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Abstract—Reflected infrared imaging has been used as an investigation tool for paintings and paper conservation since the 1930s. The technique can reveal underdrawings, expose compositional changes, provide information about manufacturing process and technique, and differentiate materials. As digital camera technology and computing have evolved, the technique has continued to advance, improving the applications for cultural heritage documentation. However, there is very little published on the use of the technique for three-dimensional cultural heritage object documentation. The term *object* refers to three-dimensional works of art that include archaeological, ethnographic, historic, sculptural, decorative, and contemporary arts, composed of a wide variety of materials and combinations of materials. Some of these materials are similar to those in paintings and others are quite different, and the optical properties of the materials influence the interaction with infrared radiation and the imaging results. This paper looks at the current applications of reflected infrared imaging in conservation and research documentation and explores the fundamentals of why the technique is successful and how that success might transfer to the documentation of 3-D objects. Examples from an imaging case study with the Freud Museum are included to illustrate the arguments.

Index Terms—infrared; imaging; cultural heritage

I. Introduction

Digital imaging techniques, using non-destructive and predominately portable investigation tools, are important for the research and conservation of cultural heritage (CH) materials. These imaging techniques are important for recording the condition, informing the care and treatment, and increasing the understanding of objects. Infrared (IR) radiation has been used for CH documentation since the 1930s when film sensitive to near-infrared (NIR) radiation (up to ~ 900 nm) became available [1]. This technique is based on recording the varying reflection, transmission, and absorption of IR radiation by the materials present in an object. The technique has become established for paintings and paper conservation as it aids in examining underdrawings, detecting composition changes, and enhancing the visibility of obscured or faded texts.

This paper focuses on the documentation techniques in the regions of NIR (700-1000 nm) and shortwave infrared (SWIR; 1000-2500 nm) (Fig. 1). Following the designation in [2] for the NIR and SWIR regions and the differentiation of technique terminology in [1], *reflected infrared photography* uses wavelengths in the NIR region and corresponds with the sensitivity of IR sensitive films and digital cameras with silicon detectors, while *infrared reflectography* (IRR) uses wavelengths in the SWIR region (1000-2500 nm) and requires specialized sensors.

While numerous studies on reflected IR imaging are widely available for paintings and paper conservation, there are few studies that have examined reflected IR imaging of objects. The term *object* refers to three-dimensional works of art that include archaeological, ethnographic, historic, sculptural, decorative, and contemporary arts composed of a wide variety of materials and combinations of materials. This paper presents current applications of reflected IR imaging in conservation and research documentation looking at the fundamentals of why the technique is successful for some materials, such as paintings, and how that success does and does not carry over to the documentation of 3-D objects. This is illustrated in a case study of IR imaging of objects at the Freud Museum.

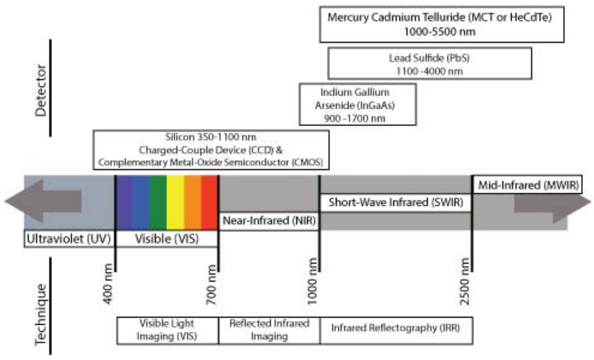

Fig. 1. Detail view of the electromagnetic spectrum focusing on the NIR and SWIR region with wavelength ranges (middle), detector types (top) and techniques (bottom).

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II. IR Techniques and Technologies

In the 1930s IR photography was adopted from experimental applications by commercial photographers and incorporated into the field of conservation as an investigation tool. Initially it was used for the investigation of censored, damaged and forged books and documents, applications that easily transferred to museum objects and authenticity studies [3]. Extending the spectral range up to about 2000 nm, Van Asperen de Boer introduced the use of Vidicon video tubes for IRR for the examination of paintings in the 1960s. [4], [5]. The system presented a higher spectral resolution than film, and increased the speed and ease of acquisition by providing a direct visualization on a monitor. More recently, the introduction of digital cameras and the development of various sensors greatly improved IR imaging techniques and documentation for CH by increasing the spectral sensitivity and the image quality [6]. These materials included the silicon charged-couple device (CCD) and complementary metal-oxide semiconductor (CMOS) sensors, the indium gallium arsenide (InGaAs) sensors, and the mercury cadmium telluride (MCT or HgCdTe) sensors. Silicon sensors (350-1100 nm) are sensitive to the NIR region, while InGaAs (900-1700 nm) and MCT (1000–5500 nm) sensors are sensitive to the SWIR region (Fig. 1) [7], [8].

One of the current areas of research and development in CH is imaging spectroscopy (IS), which is the integration of digital imaging and reflectance spectroscopy. Imaging spectroscopy extends the point-based spectroscopy techniques to two-dimensions to document an entire surface and provide an individual spectrum for each pixel [9]. In addition to pigment identification from spectral reflectance, NIR and SWIR images can be acquired at different wavelengths or bandwidths as part of multispectral and hyperspectral image cubes revealing underdrawings and compositional changes. Recent examples of IS techniques incorporating the SWIR region to investigate paintings include [10] and [11] and [12] for the investigation of illuminated manuscripts.

III. Applications for Paintings and Paper

The most common applications of IR imaging in conservation documentation are for the investigation of paintings and paper for detecting underdrawings, investigating compositional changes, differentiating materials, and enhancing the visualization of obscured or faded text [1]. Mairinger [13] included IR imaging examples that differentiated inks in graphic arts; increased legibility of obscured and faded texts; detected alterations, repairs, and underdrawings in paintings; differentiated materials on dyed textiles; and revealed obscured designs on pottery fragments. Gavrilov et al. [14] used three IR techniques for the investigation of underdrawings and subsurface degradation of paintings. Arslangoglu et al. [15] included IRR as an investigation technique as part of an analytical study for paint identification in Picasso's paintings. Gargano et al. [16] discussed visible and NIR techniques for enhancing text in ancient documents. The recently published *Science and Art: The Painted Surface* [17] has four chapters that include IR imaging as components in scientific investigations of paintings.

The examination of underdrawings with IR radiation originated in investigations of medieval paintings as described by Van Asperen de Boer [5]. Infrared imaging revealed underdrawings in paintings dating from the 16th century and earlier because the drawing materials used tend to be carbon-based, which absorb IR radiation, and are applied to chalk or gypsum grounds that are highly reflective to IR radiation [21]. As painting techniques evolved, some underdrawing materials were no longer carbon-based and the ground was not always an IR-reflective chalk or gypsum. In these cases low contrast between the materials prevented IR imaging from revealing underdrawings [21].

Infrared imaging in paintings conservation has become an established technique because of the known optical properties of the ground layer, the materials used for underdrawings, and the pigments [4], [5]. Van Asperen de Boer provided equations for calculating optical properties of pigments within the constraints of medieval paintings. Specific pigments and known interactions with IR radiation are discussed in [14]. Gargano et al. [22] provided a table with transparency measures of some pigments using five different IR systems. Delaney et al. [23] established the optimal visibility of underdrawings around 1800 nm.

IV. Applications for 3-D CH Objects

There are few published examples of IR documentation of 3-D objects. However, these techniques are most likely used at least occasionally as an investigation tool. Gibson [3] claimed that routine applications of IR imaging in forensic and museum applications that had been included in earlier literature are no longer discussed because they are now routine. Some of the available references include Moss [18] imaging repairs on a lustre jug, and Gibson [3] referencing studies with metals, a wooden object, stained glass, and cave paintings. In Mansfield et al. [19] and Warda et al. [1] applications beyond paintings and paper were alluded to, but specifics are not given. Falco [20] included a single example, a set of Japanese armor, where the technique was used for material identification.

The generalized term of CH objects encompasses a wide variety and combination of materials, which contrasts with the more limited number of materials used to create paintings. This variety and combination makes it challenging to understand all the optical properties and the possibilities for reflected IR imaging results. The manufacture of 3-D objects does not necessarily have the prescribed stratigraphy as that of paintings (ground layer, underdrawing, paint layers), which established the application of the technique for paintings documentation and the investigations of underdrawings. Focusing on a collection or objects of similar materials, would help to limit the variables being investigated and could provide a better understanding of the potential results for IR imaging of 3-D objects.

V. Case Study: Freud Museum, London, UK

An initial case study was conducted at the Freud Museum (London, UK) to better understand the use of reflected IR imaging for the research and conservation documentation of

3-D objects. The Freud Museum has a collection of nearly 2000 Egyptian, Roman, Greek, and Oriental antiquities that were collected by the psychoanalyst Sigmund Freud. This case study involved documenting 20 collection objects with reflected IR digital photography using a modified Canon 5D Mark II with the Coastal Optics 60mm UV-VIS-IR lens (Jenoptik Optical Systems, Jupiter, Florida, USA). Modifications to the camera included the removal of the IR-cut filter and the color filter array (CFA) by MaxMax LDP LLC (Carlstadt, NJ, USA). The modified camera's sensitivity extended up to about 1100 nm and a Peca 906 filter (Peca Products Inc. Beloit, WI, USA) was used to block wavelengths below about 950 nm. The objects were illuminated with two Lowel ViP Pro-light tungsten halogen lamps (Tiffen, Hauppauge, New York, USA). Visible light images were acquired for reference, comparison, and analysis. These images were acquired using a Canon 5D Mark II with the same lens and light as the IR imaging. The visible light and reflected IR images were compared to better understand the potential of the technique for documenting 3-D CH objects. Three examples are presented including a Greek vessel and two wooden Egyptian sculptures with pigmentation.

The first object is a 5th century BC Greek lekythos (LDFRD 3702), a ceramic vessel listed as 'black figure' that depicts two warriors walking beside their horses (Fig. 2) [24]. The lekythos appeared to have been reconstructed from many pieces with parts of the warriors, horses, and the design obscured by the reconstruction materials, and natural fading and wear. The reflected IR imaging enhanced the contrast and view of the design despite the surface obstructions (Fig. 2).

The second object is a Human Headed Ba-Bird (LDFRD 3286) from the Ptolemaic Period (332-30 B.C.) (Fig. 3). It is a wooden figure with gesso and paint [25]. The figure is thought to have once been a part of a rounded wooden funeral stele and representative of the "ba", which along with the body and the life force are the three elements that a person was divided into at death [25]. The "ba" can be represented in the form of a bird to return to the land of the living [25]. The reflected IR image increased the visibility of cracking in the areas of dark pigment providing more information about the objects condition (Fig. 3).

The final object is an Osiris statuette (LDFRD 3123) made of wood and simply listed as "painted with base" (Fig. 4) [26]. The object was selected for investigation because the design and characters painted on the wood are obscured and worn. Reflected IR imaging enhanced these details, providing further information for a researcher or heritage professional.

The provenance of some objects in the collection is not well known, so the IR imaging results cannot be linked back to the optical properties of specific pigments, adhesives, and other materials. The results are instead a more general statement for the argument of using reflected IR imaging for the documentation of 3-D objects. This imaging case study has provided evidence that reflected IR imaging can increase the visibility of obscured details and reveal surface features that indicate the condition of the objects.

VI. Conclusions

The success of the IR imaging for investigating paintings results from a highly reflective ground layer contrasting with the IR-absorbent underdrawing materials and the transparency of paint layers. However, IR documentation of 3-D CH objects instead investigates materials and manufacture techniques and is not dependent on the same structure as paintings. Reflected IR imaging can provide increased visibility of obscured details, differentiation of materials, documentation of condition, and additional information about the materials and manufacture of 3D CH objects. In the future, a comprehensive resource of NIR and SWIR imaging may provide a better understanding of the interaction of general materials, like wood, metal, ceramics, etc., and IR radiation. This will require further research in imaging and analysis of 3-D CH objects and comparison of reflected IR imaging (NIR) and IRR (SWIR) to determine if the expanded spectral range provides additional insight about the materials, manufacture and condition of 3-D objects.

Fig. 2. Greek lekythos (5th century BC), detail. VIS (left) and reflected IR (right) showing the enhanced view of the vessel design and depictions.

Fig. 3. Human Headed Ba-Bird, detail. VIS (left) and reflected IR (right) showing the increased visibility of the cracking in the areas of dark pigment on the head.

Fig. 4. Osiris Statuette, detail. VIS (left) and reflected IR (right) showing enhanced visibility of the characters and designs.

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