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Current Approaches, Solutions and Practices in Conservation of Cultural Heritage

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CHAPTER 11

IMAGING DIFFERENT TYPES OF MATERIALS IN CULTURAL HERITAGE WITH REFLECTANCE TRANSFORMATION IMAGING (RTI) TECHNIQUE

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Abstract

Reflectance transformation imaging (RTI) technology is a method used in the visual examination and documentation of cultural heritage. The method has a fixed camera setup. The artifact, which is placed opposite the camera, is illuminated from different angles using fixed equipment or labor. One photograph is taken for each angle of illumination. The photographs are processed with the help of software, and the color and shape information is saved in a file. Thanks to the advanced functions in the computerized imaging software, surface features and color information can be changed to bring to the fore details that would not be noticeable under normal conditions. The method can be used to document various works and contribute to the investigation of construction techniques and deterioration before restoration and conservation works. Fixed hardware was produced for use in this study. The body of the hardware is geodesic-dome-shaped. The LED lighting on the dome worked synchronously with the shooting device by communicating wirelessly. Using this equipment, ceramics, oil on wood, metal, and paper materials were imaged using the RTI method. Imaging different types of materials allowed us to compare the success of the method on different surfaces. At the same time, the method is expected to highlight the traces caused by production on the surface and the physical damages that occur afterward. The fact that various works had suffered some damage was considered to examine their construction techniques and distortions and that the color-shape properties were variable in object selection. The possible contribution of this method to conservation and restoration studies can also be evaluated.

Keywords: Reflectance transformation imaging, geodesic dome, conservation, cultural heritage

1. Introduction

Cultural heritage has a natural aging process. The aging process and the factors affecting this process cause changes on the surface of cultural heritage. Discoloration, abrasion, loss of parts, scratches, pitting, crusting by chemical effects, corrosion, and cracking are some of them. Assessing the current status of cultural heritage is important in determining the cause of its deterioration, protecting the work, and determining the repair method. The limits of the human eye require tools that can collect information from the surface. In this regard, reflectance transformation imaging (RTI) provides a virtual vision of the surface of artifacts by processing surface normals and color information. With the RTI method, oil paintings, textiles, paper, ceramics, metal, stone, wood, and many more can provide data on their surfaces. In works with complex textures and surfaces, such as oil paintings, the ability to extract color information from images makes abrasions and brush strokes visible with the movement of light. In addition, on surfaces with layered and rough textures, such as ceramics, much data from tool marks to layer losses can be provided by this method (Manrique-Tamayo et al., 2013).

2. RTI method's working principle

The RTI method, which is based on photometric stereo technology, does not use 3D geometry. In the RTI method, while the displayed object and the camera are stationary, the position of the light illuminating the object changes. Photographs are taken by illuminating the subject from different positions, and the surface reflection of the object is obtained by combining these photographs. The abbreviation RTI is used not only for the method but also for the format of the file obtained by using the method. In 2000, Tom Malzbender of HP Labs introduced Polynomial Texture Mapping (PTM), an alternative for compressing surface properties. Later on, at the University of Minho in Portugal, Cultural Heritage Imaging (CHI), together with a funded project contributed by the CHI team and Tom Malzbender of HP Labs, the open-source software package RTIBuilder was developed (Earl et al., 2011, pp. 147–148).

The RTIBuilder software can be downloaded from the CHI website. With this software, two different image processing techniques are presented to the user: PTM and RTI. In both methods, black or red spheres with a glossy surface that can be clearly seen are placed in the frame when the photograph is taken (Fig. 1). The developed software captures the reflection of the light hitting the placed spheres and determines from which direction the light hits the sphere. Known light directions can be processed by two different algorithms and saved as RTI or PTM file extensions. RGB values are recorded for each pixel in the file (excluding lighting conditions) (Mudge et al., 2012, pp. 644–648).

The angle between the surface of the lights to be used in the RTI/PTM method should be between 15° and 65°. The light sources should be positioned at a distance of two or four times the diameter of the object being imaged. A minimum of 16 images are needed to obtain an RTI/PTM file, and 24–60 images are enough to achieve a successful result. Meanwhile, hemispherical harmonics is a newer technique and gives better results on 3D surfaces. In this technique, the accuracy of surface normals is higher. However, when examining the image with the PTM technique, the software allows more tools to be used (Duffy et al., 2018).

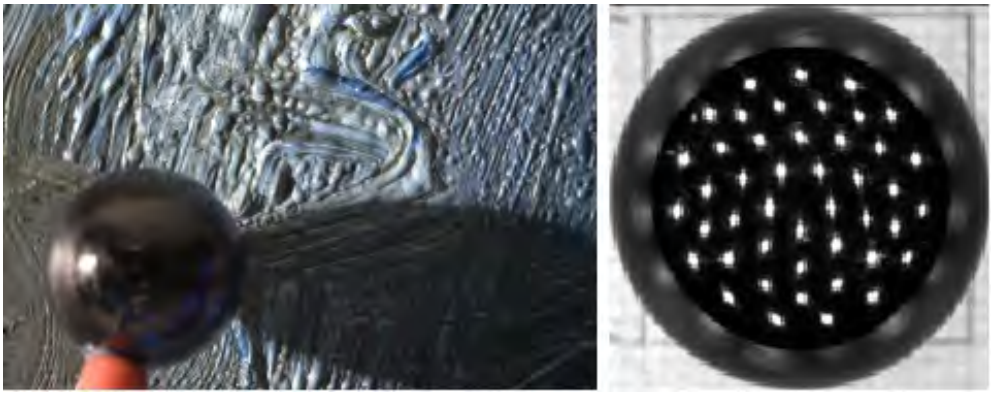

Figure 1. A sphere placed on the photographed surface (left) and the sphere (right) where the light reflections are combined in the processed image. (http://www.c-h-i.org/learn/media/RTI_Hlt_Capture_Guide.pdf) (Tamayo Manrique et al., 2013, p. 545)

2.1. Fixed equipment

Hardware with fixed light sources ensures fast and consistent viewing. Light sources can be positioned in hemispherical or geodesic domes. It can also be placed on fixed arms surrounding a camera (Earl et al., 2011). This equipment can be produced in different sizes according to the surface area of the work to be displayed. However, the area displayed by the camera should be at least 1/3 of the size of each dome. In domes that are not produced three times the size of the imaged area, the reflection of light cannot be calculated correctly. Light sources can be selected by the hardware manufacturer without being tied to a specific standard. The choice of camera and lens is also determined according to the needs of the practitioner. These variables affect the color accuracy and depth of field. The camera placed at the top of the dome and the light sources placed at fixed distances are automatically triggered. The placed light sources are usually divided into 12 arms with the camera in the center. Three or four tilt points should be determined for each arm, and the light sources should be placed at these points. However, different designs are also available (Fig. 2). Although the

light placement, number, and temperature vary depending on the equipment, only one light source is active each time the camera is triggered. In addition to complex electronic systems, cost-effective codable electronic cards can also be used for triggering (Bentkowska-Kafel, 2018; Cultural Heritage Imaging, 2013a).

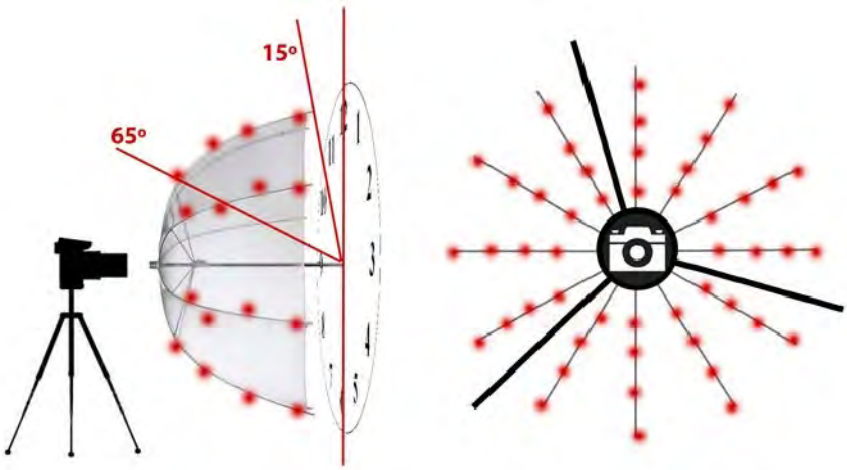

Figure 2. Schematic representation of the light layout of the dome. (http://culturalheritageimaging.org/What_We_Offer/Downloads/RTI_Hlt_ Capture_Guide_v2_0.pdf.)

In low-cost hardware, the trigger is usually provided by Arduino boards and the illumination is provided by codable LED lights. These circuit boards can trigger any type of lighting used simultaneously with the camera. In the display of small-sized works, addressable strip LEDs (WS2812B) that Arduino boards can power are preferred (Fig. 3). Such lighting includes integrators that can be coded in each LED. Because a 5-V power supply provides enough energy for both Arduino and LED, there is no need for an extra power supply in the system. It also allows the installation of portable systems without the need for complex wiring or an external electronic card. However, the white color produced by the LEDs in this system does not have high accuracy. Meanwhile, addressable LED, which consists of three diodes emitting green, red, and blue colors, cannot provide homogeneous white color distribution. In this regard, a color calibration table can be placed in the photo frame to eliminate color-related problems. Color calibration can be performed with software support. In large-sized equipment where high light intensity is required, chip on board (COB) technology is used. COB illuminations operate at high lumen values. These can be produced with different voltage, amperage, and temperature values. Such LED lights must

be triggered externally as they do not have built-in integrations. Arduino and similar various electronic boards can be used for triggering.

There have been many studies on hardware in these applications. Although the shape of the hardware varies, the orientation of each light source must be centered. Half-dome-shaped hardware is often preferred for this reason. With the ease of the manufacture and use of this hardware, geodesic hemispheres have become popular. The connection points of geodesic domes and the middle parts of the interconnected apparatus are suitable for use by directing light to the center (Fig. 4). Online software that can do calculations for the production of geodetic domes and connection apparatus in accurate dimensions is also available. The materials used in the production of the dome also vary, but the interior is usually made of black matte materials to prevent light reflection. There should not be any light source in the environment that may cause misleading reflection other than the lighting of the hardware. Thus, the outer part of the dome is closed with materials that will not pass light (Kinsman, 2016; Corregidor et al., 2020).

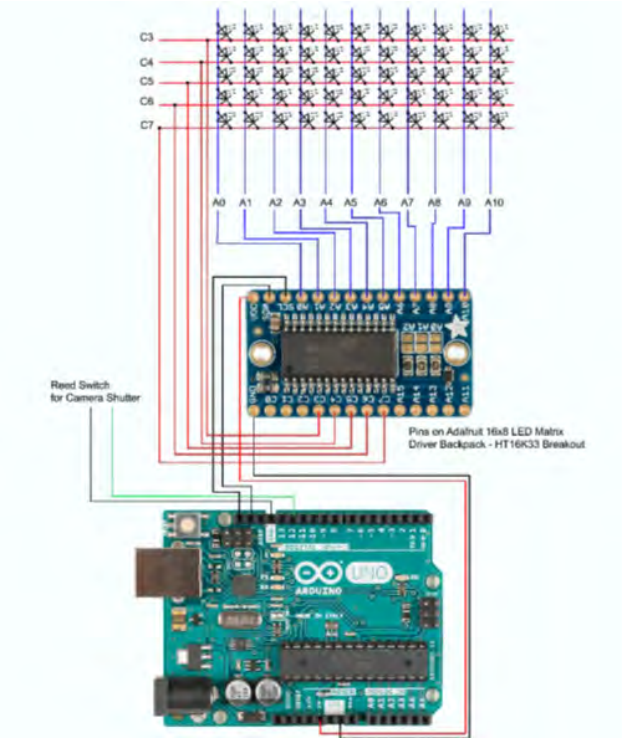

Figure 3. Automatic trigger system installed with Arduino and LED matrix circuit boards. (Kinsman, 2016)

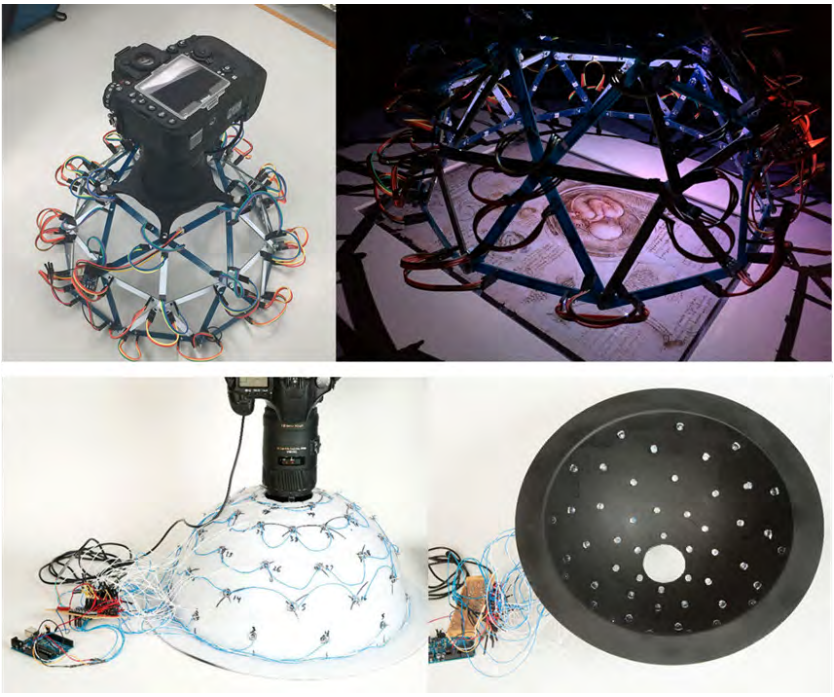

Figure 4. Geodesic dome (top) and hemispherical dome (bottom). (Kinsman, 2016, pp. 12–13)

With stationary equipment, there is no need for black or red glossy spheres used to calculate the angle of light. After processing a series of images shot with fixed hardware with the RTIBuilder software, creating an LP file and defining this file to the program are sufficient as the direction of the light does not change in subsequent studies.

2.2. Manual imaging

Although fixed hardware provides speed and high accuracy, imaging can be performed without the use of such systems. In this method (where the camera is fixed), the light is moved manually for each photo. Para flash or continuous light sources can be used (Fig. 5). Spheres with black or red glossy surfaces are placed close to the subject so that they enter the frame. Then, at the same distance from the center, the light source is reflected on the object's surface from different angles. In each frame, the light source causes a point-shaped reflection on the spheres with a bright surface. These reflections can be determined by the algorithms of the RTIBuilder software, and the stroke angles of the light can be determined. When applying the method, the distance of the light from the center is different in each frame and the overlap of the reflections in the spheres with bright surfaces causes errors in the RTI file (Earl et al., 2011, pp. 149–150; Cultural Heritage Imaging, 2013a).

Figure 5. RTI shooting without fixed hardware. (Schroer, 2012)

2.3. Microscopic imaging

To obtain microscopic images using the RTI method, optical microscopes capable of zooming with a large working area are needed (Fig. 6). In this method, spheres with black or red glossy surfaces are required to calculate light angles. When shooting with a microscope, a dome shape can be created or the subject can be illuminated from the desired distance and angle with a small light source (Min et al., 2021; Earl et al., 2011).

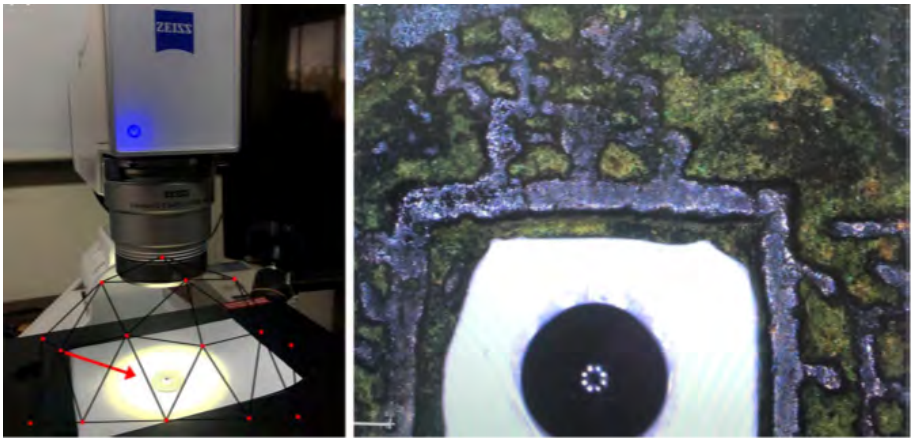

Figure 6. Microscope used for imaging, geodetic reference points created for the light (left), and details of the surface being imaged (right). (Min et al., 2021)

2.4. Image processing and inspection

A series of images obtained by automated or manual systems were processed using algorithms owned by the RTIBuilder software on the CHI team's website. The software, which can work with Windows and MacOS operating systems, supports RTI and PTM technologies. The processed images were saved with file extensions of the same name according to the preferred method. Because the PTM algorithm is patented by HP Labs, it was not included in the RTIBuilder software package. The display of the files used RTIViewer software, which can be downloaded from the CHI team's website.

The RTIViewer software includes a virtual light router that allows changing the angle of the light hitting the object. The software provides different reflection characteristics by editing RGB color information and surface normals. In this way, more details can be displayed than those of software that filters with color data. Depth perception can be increased by changing the surface slope using the diffuse gain tool (Fig. 7). Using the specular enhancement tool, surface distortions that are difficult to see on very glossy or matte surfaces due to color information become visible by removing the RGB information from the image and moving the light in the desired direction (Cultural Heritage Imaging, 2013b) (Figs. 8 and 9).

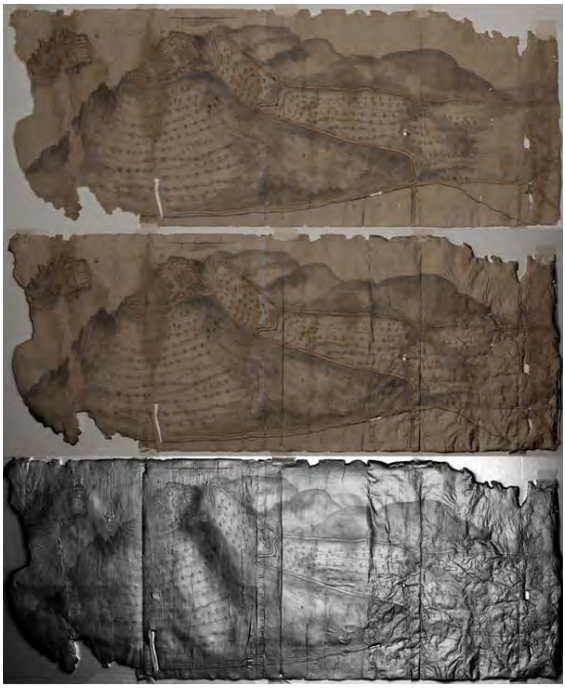

Figure 7. Viewing a watercolor work in plain light (top) and at the same light angle as the diffuse gain tool (middle) and specular enhancement tool (bottom). (Tamayo Manrique et al., 2013)

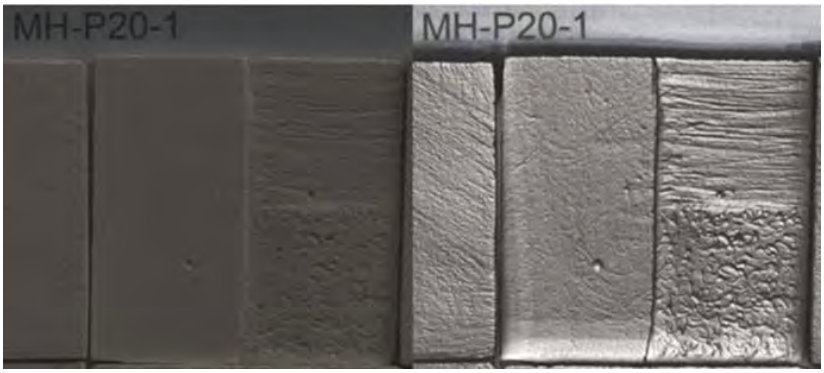

Figure 8. View of bone tissue under normal light (left) and after processing with RTI (right). (Tamayo Manrique et al., 2013)

Figure 9. A piece of ceramic depicting Dione and Aphrodite under normal light (left) and after processing with RTI (right). (www.timesofisrael.com/imaging-technology-reveals-birth-of-athena-on-2300-year-old-shard-from-galilee/.)

3. Investigation of dome imaging on various materials

Within the scope of the broadcast, ceramics, paper, metal objects, and one oil-on-wood work were imaged using the RTI method. The equipment used in the display was a geodesic dome with 60 LED light sources and was manufactured by us (Fig. 10). The geodesic dome used in the shootings was low-budget, and various surfaces were imaged with RTI using this equipment.

3.1. Dome structure

The use of low-budget equipment and the results obtained show that advanced imaging techniques can be applied without high costs in the imaging of cultural heritage. A smartphone camera, 60 codable LEDs (WS2812B) for lighting, a Bluetooth trigger to control the smartphone camera, and an Arduino UNO to control all this hardware were used to obtain the images. The shape of the structure where the codable LEDs were positioned was geodesic. The preference for this shape was because the distance of the LEDs from the center of the dome must remain constant. The body of the geodesic dome consisted of compressed paper. Such a material provided both sufficient body strength and a lightweight structure. Starting from the base of the 60 LEDs on the dome, they illuminated the object from different angles for 2 s in turn. The LEDs were controlled with the help of an Arduino-based microcontroller. Arduino UNO can be coded with a software installation tool, and tasks can be assigned to the hardware to be triggered. The flashing speed of the LEDs can be customized according to the camera used with corrections to be made on the software.

The designed geodesic dome had two shooting modes. One of the two buttons on the dome's control was coded to trigger all LEDs, whereas the second button was coded to not trigger 10 LEDs close to the floor. The second button, which allowed shooting with 50 LEDs, was used to display three-dimensional subjects. Otherwise, an apparatus was needed to raise the dome. The color, light intensity, and light temperature can also be changed by coding the microcontroller. In this way, a more flexible working opportunity was created to emphasize the details of the object being imaged. The Bluetooth trigger in the hardware received commands from the Arduino UNO microcontroller. It was triggered 1 s after the smartphone camera started being illuminated by each LED. This allowed time for each photograph to allow the camera to receive sufficient light. The flashing times of the LED light sources during shooting and the trigger time of the Bluetooth module could be adapted to the exposure time. A 5-mm black ball earring with a glossy surface was used so that RTI algorithms could predict the direction of illumination. A 5-mm sphere was sufficient for a dome with a diameter of about 1 m. The angle of the reflections falling on the sphere could be recorded as an LP file. In this way, there was no need to use a sphere for each shot on the fixed equipment. Defining the LP file in the program while processing the images shortened the processing time.

The features of the hardware could be arranged according to the need through the software. Because it has an easy installation, it can be updated to shoot ultraviolet or infrared.

Figure 10. RTI dome in the geodesic structure. (Photo. Emirhan Çetinkaya)

3.2. Viewed materials and reviews

The handmade ceramic object in Figure 11 had a height of 12 cm. The RTI file of the ceramic object was created using a total of 50 photographs. In examinations made with color information, the details on the surface became visible at different light angles. The RTI image of the object gave information about the tools used and their angle of use and shape. At the same time, fingerprints could be seen in detail. The emphasis on detail could be replaced by the tools available to the RTI Viewer software. When the surface properties were examined with the specular enhancement tool without color information, the depth of the traces created by the instruments became clear. At the same time, the illusion created by glossy or matte areas was minimized. With the examinations, one fracture was seen in the arm and leg parts of the object. The lines on the legs were made with the help of a tool, and their depth differed from that of the fractures. The lines on the body had variable depths and angles. The tool depths show that about three different tools were used to make the object (Fig. 12). Fingerprints seen in areas where tool

marks were not dense show that these areas were shaped by hand. This recording of fingerprints by the RTI method could also contribute to the work of researchers working in this field. The method allows a qualitative examination of the object because it does not provide metric data and does not contain precision. However, with the data obtained about the details of the object, one can comment on the construction technique and the deformations it has undergone. On this basis, this method can be considered a safe method that can be used in due diligence in ceramic works that have already been repaired. In particular, it can be a useful method for comparing damages before restoration, the applications made during restoration, and the physical changes that occurred on the surface after restoration. Routine checks can also be observed with a fixed dome and camera parameters. Images can be obtained with embossed surfaces or written terra-cotta works with emphasis on the desired details.

Figure 11. Ceramic object seen under flat light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

Figure 12. Detailed view of the ceramic object with the specular enhancement tool. (Photo. Emirhan Çetinkaya)

Two RTI files for the front and back of the banknote in Figure 13 were created by combining 60 images each. When examined with the naked eye, folding marks, tears, and some surface damage over time were noticeable on the surface. When the RTI image was examined, some tears were deeper and the folding marks were more than visible. In this way, details that may be overlooked during the determination of the methods and materials to be used in the repair of paper money were documented. Detecting damages on the paper surface made it possible to predict possible deterioration situations and implement preventive interventions. The physical damage caused by the areas with colored patterns and pictures on paper money was not clearly visible in the photographs. However, the specular enhancement tool included in the RTIViewer software allowed the surface to be examined without color information (Fig. 14). In this way, damage assessment images required for publication, exhibition, and documentation can be obtained. At the same time, the success of the intervention after repair applications can be documented with RTI images. In post-restoration controls, the physical results of the change that the works undergo under the influence of humidity and temperature in warehouse or exhibition conditions can be viewed using this method.

Figure 13. Appearance of the front and back of banknotes at the same light angle as the flat light (top), specular enhancement tool (middle), and normals visualization tool (bottom). (Photo. Emirhan Çetinkaya)

Figure 14. Detailed view of the front and back of a banknote in plain light (left) and with the specular enhancement tool (right). (Photo. Emirhan Çetinkaya)

To display the front and back sides of a stamp and coins in Figures 15 and 16, 50 photographs were used in the creation of the RTI file. Scratches on the surface of the coins were formed due to use. There were no mold marks as they were up-to-date materials. However, besides the traces on the stamp due to use, mold traces were also seen. These marks could be distinguished from the scratches that occurred later because they were more pronounced and deeper. Errors or marks on the mold gave information about the place of production of the coins and similar metal artifacts. Mold defects and marks on the surface of stamps can be examined together with a group of stamps of the same type and thus can provide information about their place and date of production. The surface of coin number 2 in Figure 17 shows distortion in the color images. However, when examined without color information, this deterioration did not cause any change in the surface. The physical change caused by the deterioration of the edges of coin number 1 on the surface can be clearly seen. When metal artifacts are photographed, detailed information about color change and corrosion cannot be stored. When viewed using the RTI method, the surface changes caused by corrosion can also be recorded. The extent of the damage in surface deterioration can also be monitored by this method. Thus, visual examinations using the RTI method are useful in limiting the cleaning on the surface of metal artifacts. This method can also be used to document the physical deterioration caused by different types of corrosion and to determine the intervention method.

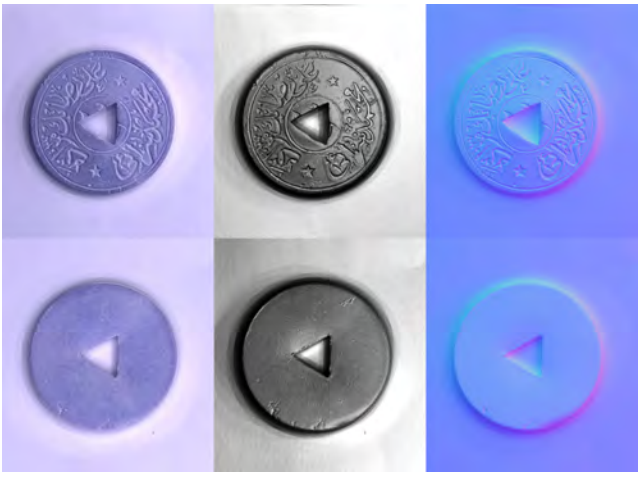

Figure 15. Appearance of the front and back surface of an Ottoman metal stamp in plain light (left) and at the same light angle as the specular enhancement tool (center) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

Figure 16. View of various coins in flat light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

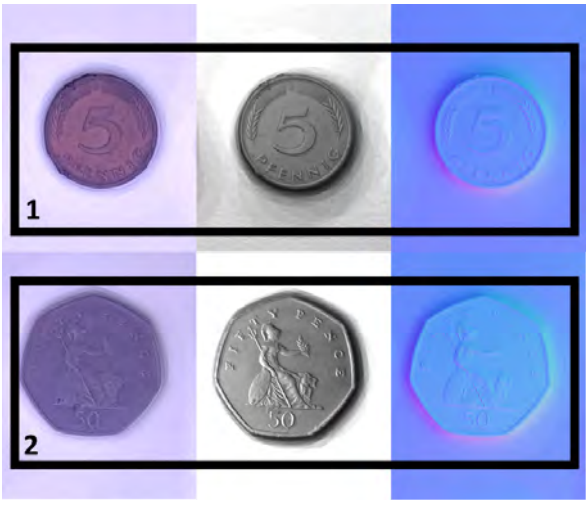

Figure 17. Appearance of coins 1 and 2 in plain light (left) and at the same light angle as the specular enhancement tool (medium) and normals visualization tool (right). (Photo. Emirhan Çetinkaya)

The RTI file of the oil-on-wood painting in Figure 18 consisted of 50 images. The surface of the oil painting work was covered with varnish. In the RTI image, when the subject was illuminated from different angles, the brush strokes and the height of the paint were noticeable. When the oil painting work was illuminated from the left side using the specular enhancement tool, the varnish dripping onto the surface became visible (Fig. 19). No deformation was observed on the surface. Macro shooting was required to examine the brush strokes in more detail. A DSLR camera and a macro lens can be used for this type of examination. The geodesic dome was strong enough to carry a DSLR camera.

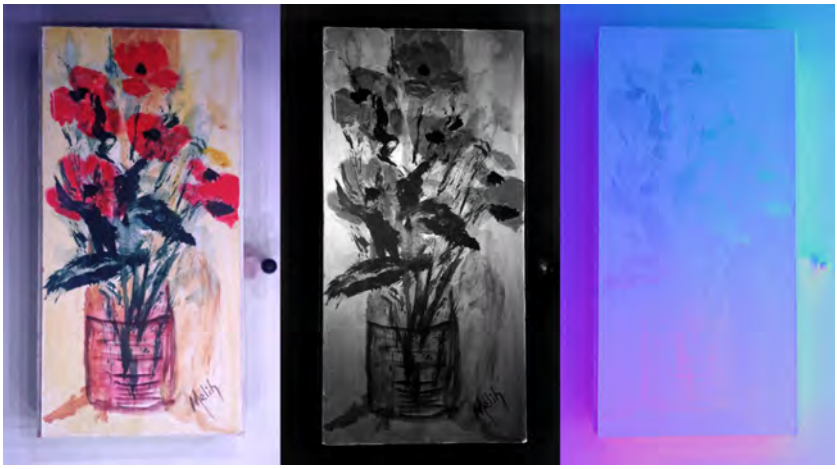

Figure 18. Oil painting on wood in plain light (left) and with the specular enhancement tool (medium) and normals visualization tool (right) at the same light angle. (Photo. Emirhan Çetinkaya)

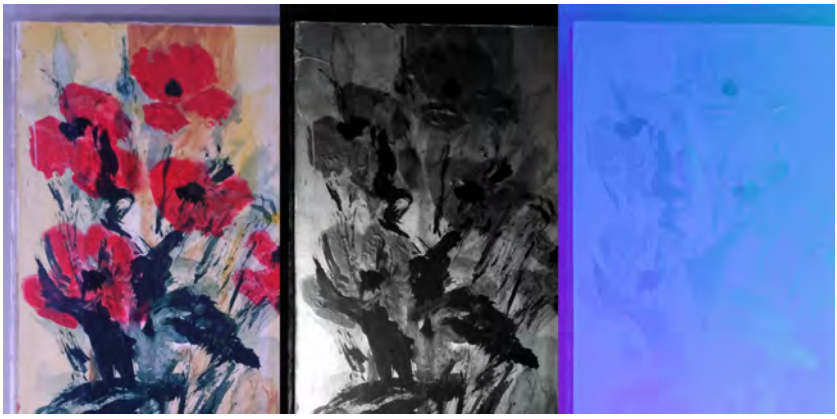

Figure 19. Paint and varnish heights in appearance with the specular enhancement (medium) and normals visualization (right) tool of the oil painting on wood. (Photo. Emirhan Çetinkaya)

4. Conclusion

RTI is a method used to examine the properties of an object's surface and to document the displayed object. Many images taken at different light angles can be stored together, and surface details that emerge in different reflection properties of the surface can be examined.

Documenting the surface properties in detail while examining cultural heritage means recording various data, such as the construction technique of the work, the tool traces used during production, the writings or signs that cannot be noticed in examinations made with the naked eye, and the destruction suffered by the surface in a single file.

The RTI technique, which is used in documenting cultural heritage, takes photographic documentation one step further by allowing the recording of not only RGB information but also surface normals. Processing recorded surface normals makes the characteristic features of the object surface apparent. This feature can be used in the examination of physical deterioration, construction techniques, and restoration interventions of cultural heritage. Precise data cannot be obtained by the method that cannot be measured metrically. Only evaluations that support scientific data can be made.

This method can be used as an alternative in archaeological excavations or laboratories where photographic documentation is conducted. The low-cost fixed installation introduced in the article allows for quick and detailed documentation in such places as it may not be possible to photograph artifacts again during excavations or laboratory work. In such cases, the RTI file has the advantage of having many images illuminated from many angles. To enrich narration in academic publications, the modes of the RTI Viewer software can be used to make the surface details more visible. In addition, RTI files can be adapted to digital publications, offering the reader the opportunity to examine various cultural works.

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