Reflectance Transformation Imaging (RTI) for Documenting Changes through Treatment of Joseon Dynasty Coins

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Research Article

Keywords: Reflectance Transformation Imaging, Documentation, Joseon dynasty coinage, Sangpyeong-tongbo, Inscription, Relief, Surface Morphology

Posted Date: March 24th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-339044/v1

Abstract

In this paper we present RTI as a documentation tool for visualizing and recording the treatment of coins. RTI, a computational photograph technique based on raking light images, allows interactive re-lighting for vision. Virtual light enhances surface details to examine morphological difference. Stages of conservation treatment were recorded to enhance characteristic features of the relief upon the coin surface and detect and identify weathered characters. Patina removal and consolidation were documented along with the original state. A significant difference in normal and surface texture was observed using RTI viewer and filters. Specular enhancement and normal visualization results were effective for detecting the change of morphology and reflectivity. Characters submersed by thick patina were revealed in Coin 3. Two hidden characters were detected as ‘[illegible]’ and ‘[illegible]’. Another illegible character which was previously not regarded as an inscription was discovered. Also, verification of each treatment stage was done to examine whether any foreign material was sufficiently removed. These documentation images indicate that RTI is a promising tool to support manual recording and furthermore allow detection of areas difficult to visualize through the human eye.

1. Introduction

Documentation is the key to accurate recording for all preservative procedures carried out starting from examination by the human eye to scientific analysis. The record itself is not only a critical information for re-treatment but also an ethical obligation for the conservator. Most documentations are supplemented with multiple photograph images and detailed writing of the artifact. However, no matter how detailed the explanation is photographed images have its limits to record accurate and specific details of the morphological surface and texture. In this respect, RTI can not only be an effective tool to aid human vision but also for recording. Reflectance Transformation Imaging (RTI) is a further developed technique based on the idea of raking light photography using Polynomial Texture Map (PTM) and Hemispherical Harmonics (HSH) [1, 2]. RTI allows interactive re-lighting of the object by saving the data of the light vector on to every pixel. Hidden details due to light and color distortion can also be revealed using RTI viewer filters. Its enhanced vision reveals shallow reliefs and reflectiveness by shading different light angles and excluding color values.

Previous studies using RTI revealed promising results on various ranges of material and type [3-5]. RTI is applied in diverse environments in the field of archaeology as a tool to record and reveal manufacture techniques [6-11]. Recently, RTI is getting noticed as a practical tool for documentation and evaluating conservation treatments [12-15]. Many cultural artifacts which have a relatively shallow surface such as documents and paintings have shown outstanding results [16-19]. Since the early development stage of RTI, ancient coins have been an interesting target for the following reasons. Coins are small to visualize the surface legend and symbols with no difficulty; has shallow reliefs which once would have been shiny and reflective, however, now a monochromatic color with a rusty surface. There have been several studies using RTI on European ancient coin produced by a hammer struck method [20-23]. However, Asian coins manufactured through sand casting has yet been studied with the application of RTI.

A coin is a relatively flat artifact with a single colored surface. Many of these ancient coins were used in everyday life as a medium of exchanging goods resulting natural wear upon the surface. Also, significant amount of time under harsh conditions leads to formation of massive patina and which sometimes are of an insidious type, causing the metal body to crumble, leaving a pitted surface. Conservation treatment and documentation are required for the preservation of these coins to stabilize the metal body and reveal historical information of the coin. Although classification and recognition of a coin can be done by a well-trained eye, under bad conditions the legends and type of coins are difficult to figure. By examining various characteristics such as color, characters or legend, techniques, shape, diameter, weight, archaeological provenance. Although these characteristics are main factors for classification and evaluation in numismatics they are often hidden under the corroded surface. These artifacts pose challenges in visualizing the surface and characters which are the main purpose of this study.

In this study, RTI is applied to examine the result of each treatment stage and to reveal information hidden under the surface. Through recording conservation treatment using RTI, the change in visual characteristics and morphological features can be maximized. Although there are few preceding studies regarding documentation, there has yet been a full research in terms of recording every conservation stage in detail and reviewing the result. In this study, three different Joseon dynasty coins were selected for conservation and RTI documentation. The individual characteristics of each coin's surface is to be examined and compared before treatment and between the stages of cleaning and stabilization. This study provides an implication for practical usage in the documentation of treatment that can be further applied in the fields of cultural heritage, modern and contemporary art. Furthermore, these multiple stacks of different light angle images can be used as a dataset for computer vision and artificial intelligence.

2. Materials And Methods

2.1. Joseon Dynasty Coin

The purpose of the minting coinage in Joseon dynasty was to overcome the constraints and inefficiency of the bartering system which more commonly collected in the form of cloth and grain. In early Joseon dynasty, a paper money was first made in 1401 and the first Joseon dynasty coinage was minted as "Joseon-tongbo (□□□□)" in 1423. After "Imjin war (1592-1598)" ended with the withdrawal of Japan, collateral damage occurred in culture and economy. One of the measures the government did was to stabilize and re-build the country was to mint coins. In 1678, "Sangpyeong-tongbo (□□□□)" were newly casted and remained widespread till 1904. In this study, we review the most common of the Sangpyeong-tongbo which are Dangiljeon and Dangijeon. These individually represent the value of one and two. All Sangpyeong-tongbo have the four identical characters □□□□ in the obverse side. Currency value, province, and the produced governmental office are embossed in the reversed side. Additionally, the reverse side may display a number or an astronomical symbol representing celestial figures, or other characters. These coins are mainly from the late Joseon dynasty period, sand casted using a mother coin for duplication as described in The Korean Review [24]. The minting technology derives from China and some raw materials were initially imported for manifacture [25]. The minting technique and components changes through the 270 years of its production and usage [26]. These kinds of coins are quite common and plenty in Korea because it was used till one century ago. Like most coins these coins were used in everyday life resulting scratches and chipped marks on the surface. Also, some areas are corroded heavily covering the characters resulting difficult interpretation.

2.2. Conservation Treatment

Conservation process was conducted in the order of cleaning, stabilizing and consolidation. A pre-examination of the current status was done to record the structure and the corrosion of the coins. (Table 1)

Cleaning of the coins were performed after examination of the current status. Tertiary patina on the surface was gently removed with a wooden pick and brush. Corrosive substances on the surface were removed with a cotton swab using abrasive (Alumina Powder 0.3μ) diluted with distilled water. Cuprite, the first product of copper corrosion was formed on coin 1 and 2 with specks of malachite, which is the secondary patina, a transformation of cuprite. Coin 3 had additional contamination over and underneath the secondary patina, mainly soil and dust with some sand in pits from the sandcasting work. Some areas where malachite was heavily formed were physically removed using dental tools and a surgical knife under an optical microscope. The chlorides were gently removed to the point where the primary patina was revealed. Residual foreign substances were removed with a soft brush using Ethyl Alcohol and Acetone and was dried naturally for more than 24 hours.

Consolidation was done to stabilize and protect the metal body and surface from further chemical reaction. To control the further activation of chloride, the coins were immersed in 3% Benzotriazole (BTA) dissolved in ethanol at room temperature. After impregnation, the surface was wiped several times and naturally dried to make sure no residue remains on the surface. The material was reinforced through treatment using Incralac (85% of acetone: toluene 1:5, 14.6% of Paraloid B-72, and 0.4% B.T.A.) which blocks re-corrosion factors, moisture and contaminated air, from the metal surface. The coins were again immersed into the Incralac for more than 6 hours to penetrate into the coin to form a protective film on the metal. The film was left to dry in a room temperature for more than 12 hours to fully dry. The coins were finally wiped with Kimwipes to prevent excessive chemicals from remaining on the surface which is the cause of unwanted glossy surface.

3. Reflectance Transformation Imaging

3.1. Dome RTI

The RTI images were captured using a Dome type RTI system. Each group of dataset has 45 images, captured with a Nikon D850 DSLR camera with an AF-S Micro Nikon 105 mm 1:2:8G ED lens. 8256x5504 pixels were attained per image with a CMOS sensor type camera. As shown in figure 1, The inner wall of the dome has a 50cm radius and 45 LEDs are attached in a geodesic order to obtain equal lighting angle and distance for every image. The LEDs have a color temperature value of 4000k. A black glossy sphere was used to register each light position to create a light position (lp) file for this array. The captures images were processed with the lp.file using the RTI Builder software, provided as an open source by Cultural Heritage Imaging [27]. The results are executable into a polynomial texture map (.ptm) format or a hemispherical harmonic (.rti) format [1, 2]. The result of the rendering process and this can be visualized through the RTI viewer. The image is able to be virtually re-lighted in different directions real time and adjust its color, texture and reflective property through filters.

3.2. Microscopic RTI

The microscopic RTI was performed using an optical microscope and a single LED as shown in figure 2. Zeiss Smart Zoom 5 was used to attain magnified images of the characters upon the surface of the coin. 1,600 × 1,200 pixels were attained per image with a CMOS sensor type camera. A 2mm(r) black shiny ball was used for the acquisition of each light position. An average of 40 images were captured for each set. The captures images were equally processed through the RTI Builder and was visualized through the RTI Viewer.

4. Results And Discussion

4.1. Documentation of Treatment Stage using Dome RTI

Virtual relighting and filters were applied to visualize the status of each coin. Yellowish brown dust piled up near and between the characters were clearly observed in all three coins. Removal of dirt from coin 1 revealed a pit which also had a different surface specularity as seen in figure 3. The dirt was very reflective compared to the surrounding regions in figure 3(a) and then was observed as a dark empty hole in figure 3(b). Also, the wide rim surrounding the characters show much deeper scratches after cleaning. After cleaning, coin 1 and coin 2 revealed minor scratches and chipped marks hidden under the foreign residue. The removal of the thick patina on coin 3 was assisted using the RTI image to detect the strokes of inscriptions. RTI image effectively shows the dynamic change of surface morphology in the reverse side of coin 3. The change in surface normal are visible in figure 4. Through the process of cleaning, the overall surface became more complexed as in figure 4(b) where more RGB colors are blended to represent the X, Y, and Z components of normal values on the surface.

The nature of sandcasting methods left an uneven surface with shallow pits made by sand grain, where abrasives for cleaning resided after polishing the coins. These areas were checked under the microscope and visualized using RTI diffuse gain filters. (Figure 5) Diffuse gain filters increase the representation of height depth where areas quickly change on the surface. In figure 5(b) dark lines visualize the difference in height depth around the areas where white alumina powder is pitted. This area was then analyzed with a scanning electron microscope - energy dispersive spectroscopy (SEM-EDS) to confirm the white residue powder as alumina. The analyzed data detected alumina (Al) as well as copper (Cu), tin (Sn) and lead (Pb). (Figure 5c, 5d) The After cleaning stage was recorded with RTI before stabilization stage to make sure that no residue was left behind, and the abrasive was removed before moving on to the next stage.

The final stage was also captured using RTI. Each stages were visualized using specular enhacement filter and normal vector map filter as in table 2. Normal vector map especially shows the change in surface pixel-by-pixel by creating a false color rendering. X, Y, and Z components of the normal are represented as red, green, and blue, for each pixel respectively. Specular enhancement visualizes different reflective properties between the proceeding stages. The original state of all three coins have a relatively matte surface due to dust and patina covering its shiny surface. Between the processing stages, the change was most dynamic in the after cleaning stage. Sharp specular regions are revealed on the characters and the outer surrounding rim of the coin and the normal vector map visualized the surface of excluded corrosive substances. The consolidation stage only shows minor difference in images, appearing dark and blurry compared to the after cleaning stage. The specularity diminishes due to the coating layer of Incralac.

4.2. Detailed Visualiztion using Microscopic RTI

Detailed images were attained using microscopic RTI with a magnification of 20 and 30 for coin 1 and 3. The letter '□' in coin 1 was acquired to examine the process of excluding corrosive substances near the upper area of the inscription. In figure 6, image (a) and (b) of the specular enhancement filter, the removed area of the corrosion is clearly visual. The area revealed was originally a negative area of the relief where rust eventually took place. Also, the removal of foreign matters is visualized in image (a) and (b) of the normal unsharp masking filter. Yellow dust was thoroughly removed from the surface. The change of the morphological feature can be seen by comparing image (a), (b), (c) in normal vector map. Shallow scratches and dents from everyday usage can be seen most clearly in (b) however less clear in (c) where the solution is coated on the surface resulting minor gaps to be filled. The change between each stage is also clearly visible in specular enhancement images where the surface of the inscription seems rather even and flat; then showing numerous scratches; lastly filling dents. However, in the surface normal image, in the case of deep scratches they are more apparent due to the filter effect.

The character '□' was revealed during the process of treatment. In figure 7 areas of corrosive substances were visualized in the normal vector map (a) where patina is seen as red. The result of the removal of cupric rust can be compared in the specular enhancement image. Horizontal strokes of the character are dramatically visualized by shading different directions of light. Specular enhancement image (b) reveals a chipped area of the lower left stroke which was not easily detected in any of the original microscopic image.

5. Conclusions

The application of RTI shows promising results in recording of broad and detailed surface. The images itself can be used as an interactive tool to evaluate the current status or the final result. For coins especially, due to their dark and bumpy surface dust, patina and the original body were difficult to differentiate. RTI imaging filters such as specular enhancement and normal map filters were helpful to measure the unwanted area of corrosives and the change of surface. Diffuse gain filters were helpful for some areas where foreign dust was piled or gathered in the surface. Also, the morphological texture of the surface was well observed in scratches and chipped areas resulting from everyday usage. Through Microscopic RTI, detailed surface changes were recorded during the elimination of rust and after coating. The after consolidation images give conservators insight on surface change such as reflectivity and applied state of coating.

For this study, the most advantageous features of RTI was in visualizing the locations of characters hidden under the patina. The documented results can also be highly practical in fast corroding artifacts excavated from harsh environment where RTI can be a sensitive tool for morphological surface and the inner metal body can be detected through X-ray equipment. Also, the plentiful number of images acquired for RTI rendering can be used as a fine dataset for the study of artificial intelligence. Classification and recognition of ancient coins are challenging laborious work for curators and registrars which require one's specialty. These coins are multiple datasets which have intra-class variability. Through training, deformed, corroded or a poorly sand casted character can be recognized. Character detection can be aided also by the difference in illumination and specular values on the character surface. one's specialtyIn future studies, we plan to use original raking light images taken by the dome RTI system and filter effect images to produce dataset. In addition, treatment stage of each characters are to be applied for the training of character recognition.

Declarations

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare no conflict of interest.

Funding

This research received no external funding.

Authors' contributions

Conceptualization, J.M. and S.A.; methodology, J.M., S. J., G.P, and J.A.; software, J.M., S.J. and D.L.; validation, J.A. and S.A.; formal analysis, J.M. and Y.C.; investigation, J.M. and S.A.; resources, Y.C., D.H., J.A. and S.A.; data curation, J.M. and S.J.; writing—original draft preparation, J.M.; writing—review and editing, D.L. and S.A.; visualization, J.M., S.J. and G.P.; supervision, D.H. and S.A.; project administration, J.A. and S.A.; funding acquisition, S.A. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

We thank Shinyoung Science and Carl Zeiss for supporting the experiment by renting us Zeiss Smart Zoom 5.

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Tables

Due to technical limitations, Tables 1-2 are only available as a download in the Supplementary Files section.

Figures

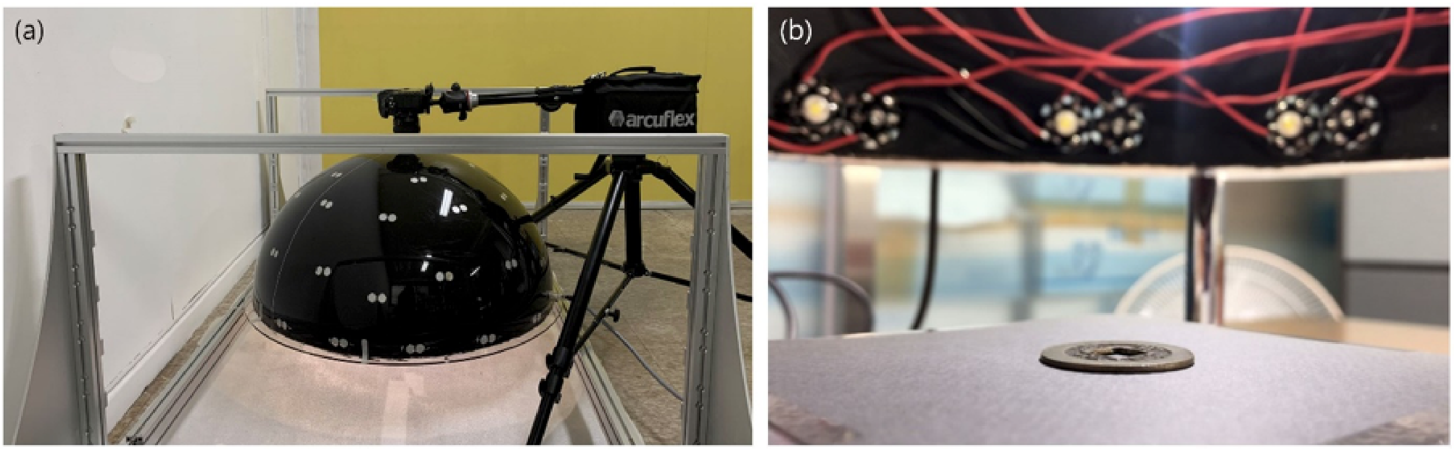

Figure 1

(a) Dome type RTI system and camera stationing; (b) Interior image of RTI shooting system

Figure 2

(a) Microscopic RTI; (b) Location to be captured under the microscope examined 20 times the actual size

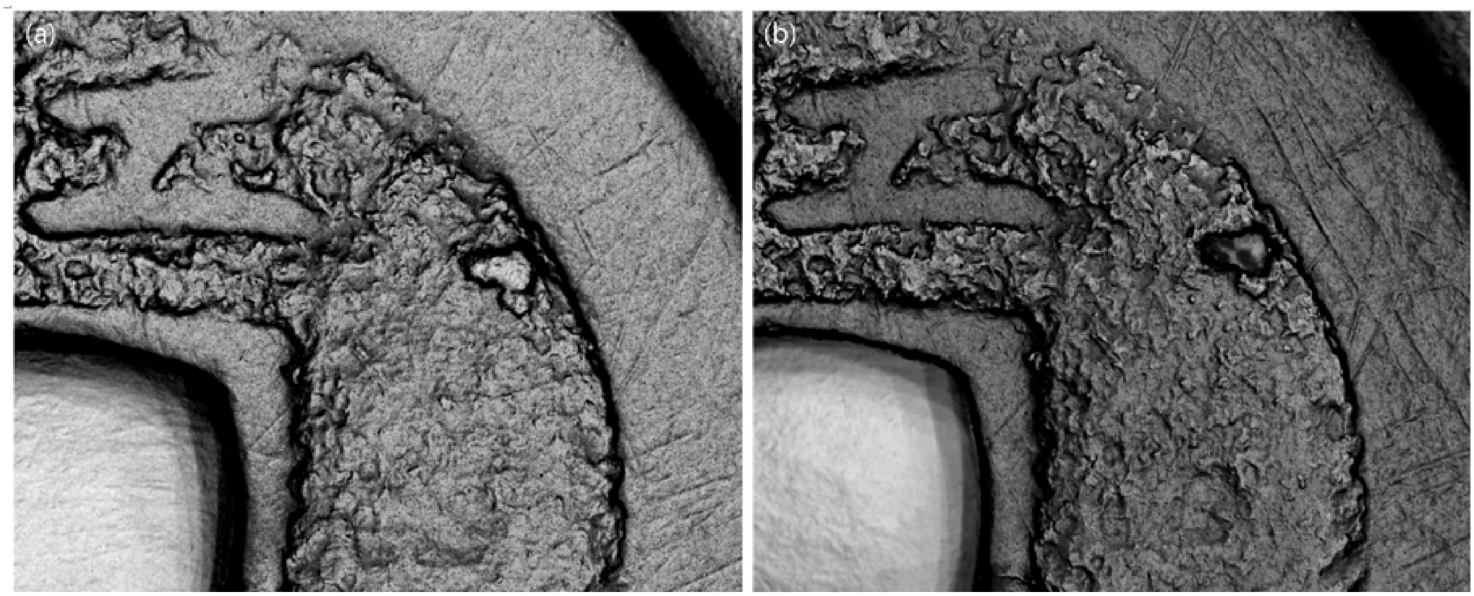

Figure 3

Visualization of dirt removed from hole in coin 1 reverse side image acquired by Dome RTI: (a) Original state and (b) After cleaning using specular enhancement filter

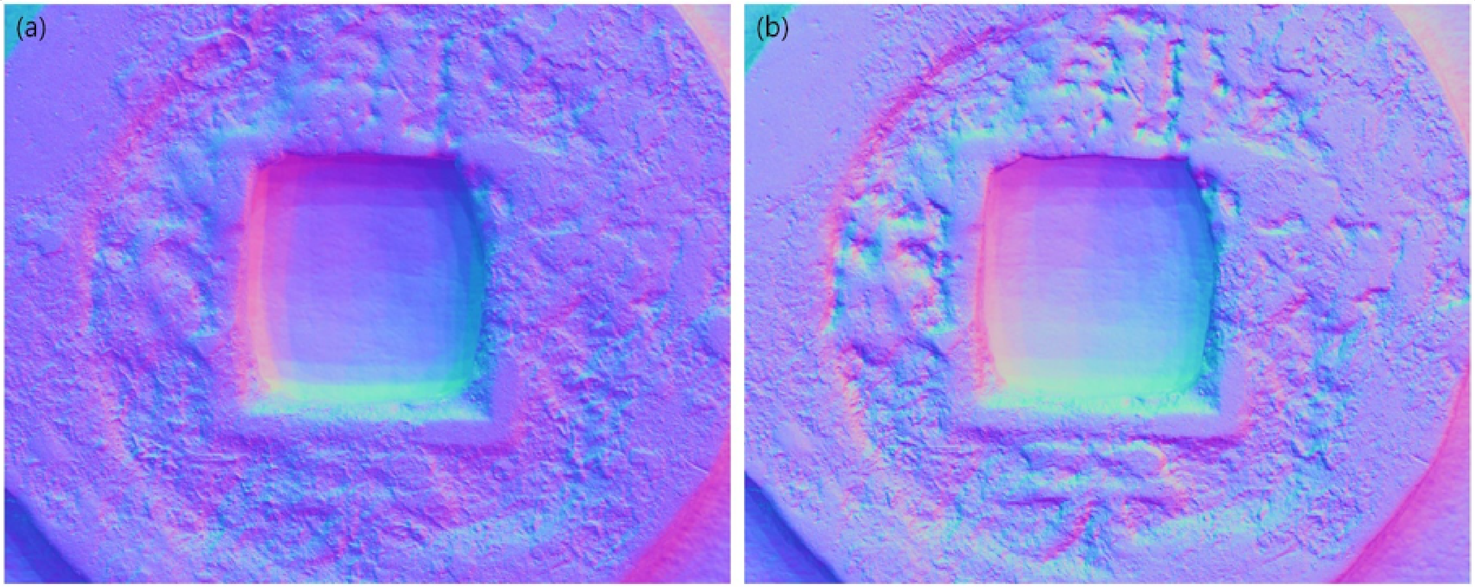

Figure 4

Change of surface morphology in coin 3 visualized by normal vector map image acquired by Dome RTI: (a) Original state and (b) After cleaning showing different normal variation

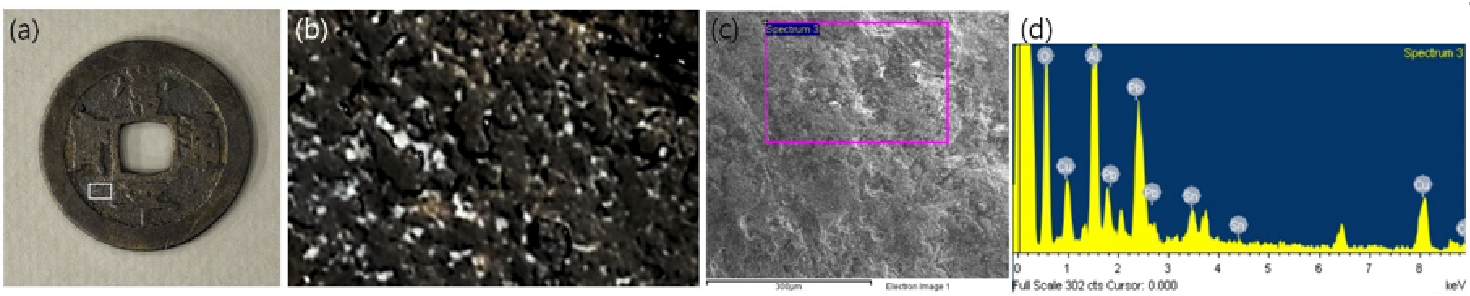

Figure 5

(a) Location of abrasive residue (b) Magnification of white box area in (a) using diffuse gain filter (c) SEM-EDS analysis of abrasive residue (d) Detected peaks of selected region where alumina spetrum (Al) is shown

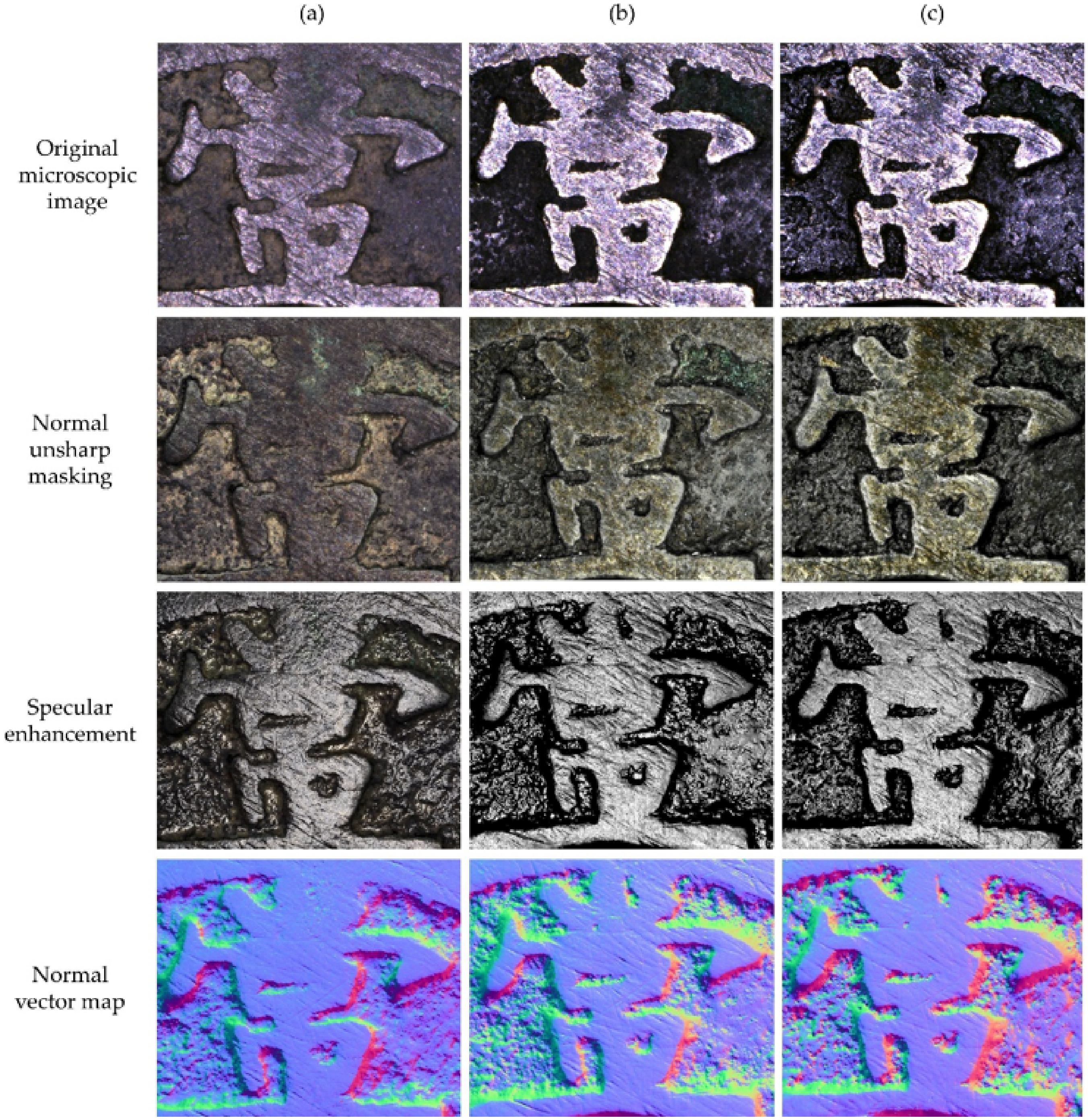

Figure 6

Microscopic RTI image of character ‘□’ of coin 1 observed with various filters: (a) Original State, (b) After Cleaning and (c) After Consolidation

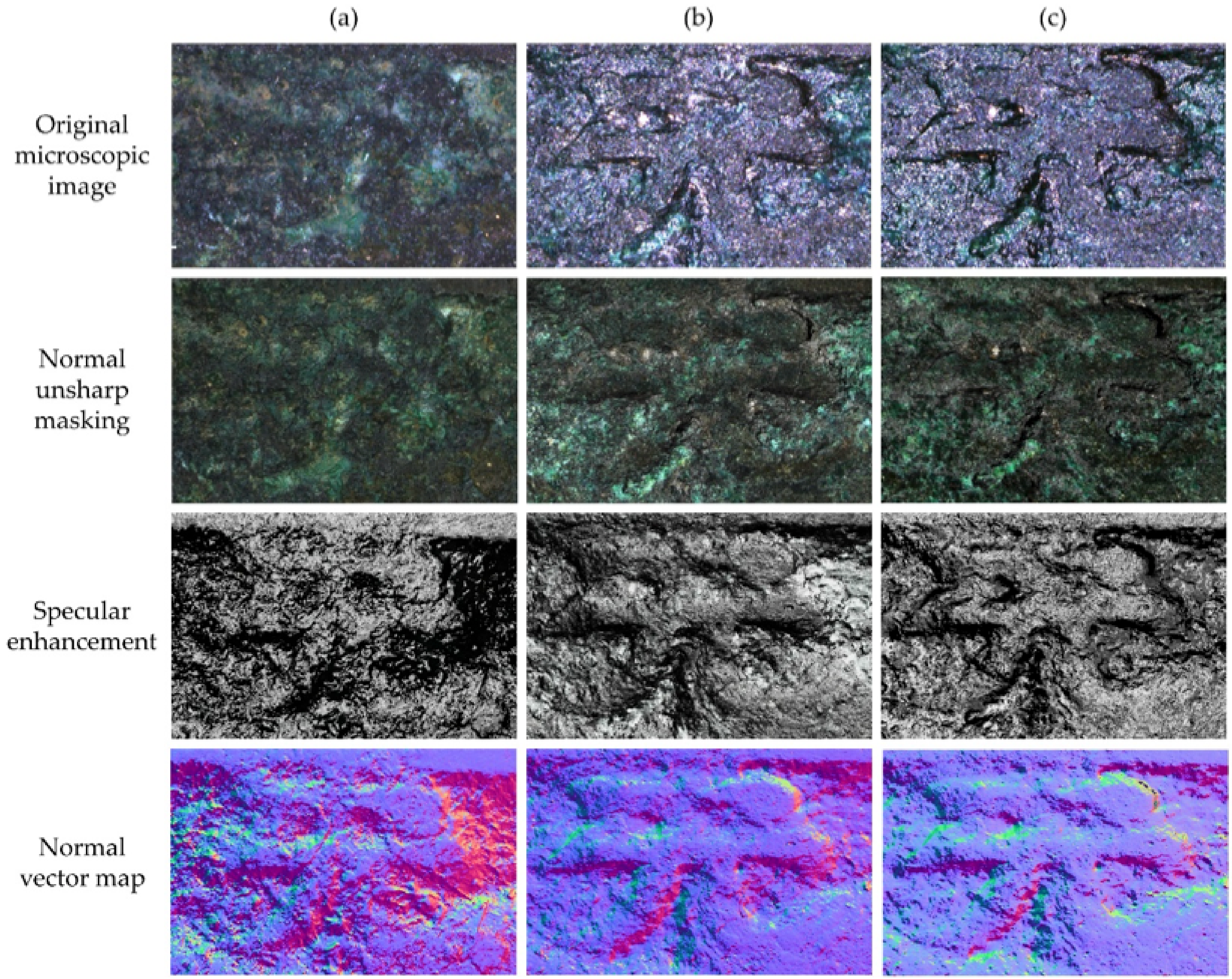

Figure 7

Microscopic RTI image of character '□' of coin 3 observed with various filters: (a) Original State, (b) After Cleaning and (c) After Consolidation

Supplementary Files

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- Tables.pdf