# STUDY OF ANCIENT GREEK AND ROMAN COINS USING REFLECTANCE TRANSFORMATION IMAGING

*By Eleni Kotoula and Maria Kyranoudi*

*Previous work on Reflectance Transformation Imaging (RTI) in the field of antiquities and works of art demonstrated the potential advantages of this technique in many areas of archaeological research and conservation. This paper presents a study on the use of RTI as a tool for visual analysis, conservation documentation and monitoring of remedial conservation operations. Tests were performed on a selection of roman or ancient copper alloy and silver coins before, during and after mechanical cleaning. The results indicated that RTI not only assists coin identification but also enables advanced conservation documentation and monitoring of cleaning operations. Moreover, RTI's use in the field of preventive conservation, as well as its significance for providing access to cultural heritage collections and in particular in the case of coin, is discussed.*

## Introduction

There is no doubt that coins pose challenges to conservators, archaeologists and historians. From an archaeological perspective, the study of coinage reveals important information related to dating, social structure, economy and politics [1]. From the conservators' perspective, the double post-excavation function of coins as resources for archaeological information and as displayable objects should be examined. Critiques towards the underestimation of the latter exist in literature [2]. However, the conservation treatment should reveal the surface morphology of coins to be legible, identified and dated, while simultaneously it is an ethical requirement to undertake all the necessary actions to preserve coins for the future and to gain maximum information from and for them. This information is not restricted in providing chronological evidence but includes information related to coins manufacture and corrosion studies. The present article discusses conservation and numismatics issues related to examination, documentation, identification and preventive conservation and proposes an affordable and easy alternative methodology, Reflectance Transformation Imaging (RTI).

RTI is a computational photography technique that enables the virtual examination of objects in front of a computer monitor. Conservators and archaeologists can observe minor details, unseen with the naked eye, holding the mouse or a tablet rather than the coin. Hence, it meets the conservation needs for limited human-object interaction, high quality and affordable visual analysis and documentation. For the purposes of the present project, a collection of ancient Greek and Roman coins was used as a case study to test RTI's efficacy in the field of coin identification, conservation documentation and examination.

## Conservation, Numismatics and RTI

### *Conservation and Numismatics*

Documentation, the accurate pictorial and written record of all procedures carried out, including analysis, examination and intervention as well as the rationale behind them, is a fundamental part of contemporary conservation as dictated by international charters. Also, guides for good practice emphasize the importance of documentation, which is an ethical obligation as it implies accessibility, one of the main objectives of conservation [3]. It is more likely for the broad scientific community to access the record of the coin rather than the coin itself. Worth mentioning is that this is also preferable from a conservation point of view, taking into consideration preventive conservation and security measures. Traditional numismatics documentation methodologies, such as photography, proved to be insufficient in recording fine surface details and visualizing the materials' optical properties. One of the most usual problems is the surface reflectivity which produces undesirable results such as distortions, reflections and shadows. This, in turn, can lead to misunderstandings for the photographed coin. Because of this, and also due to the fact that coins include thorough details, advanced recording is a necessity [4].

The identification of coins can be extremely laborious or even impossible using traditional means such as photographs, plaster casts and drawings. The most common parameters that affect coin identification are related to the coins' condition, manufacture and use. The materials' degradation, either acting additively or subtractive, can alter significantly the appearance of coins introducing changes in geometry, colour and texture. Therefore, the comparative study of coins in different states of preservation may be unsuccessful. Distortions created during their manufacture may lead to great variation, as the penetration and strike angle varies. Also, the central positioning of the figure is not certain because the procedure is performed manually. Any die damage or break adds another level of complexity in coins identification. Also, over striking is difficult to recognise and interpret [5]. Furthermore, the coins use and possibly re-use leave marks such as holes, scratches and cuts. These alterations affect coins' appearance and act as a drawback for identification purposes.

Cleaning methodologies for coins can make use of mechanical, chemical and/or electrolytic means [6]. In case of copper alloy coins, the strongest advantage of mechanical cleaning is its ability to preserve details of design, tool marks and surface finishes [7]. Taking into consideration the importance of the revelation of representations and legends on coins, it is understandable why mechanical cleaning is considered the most acceptable method for cleaning copper alloy coins: it is easy, selective and enables patina preservation [8].

***Reflectance Transformation Imaging***

Reflectance Transformation Imaging [9], including one of its subdivisions Polynomial Texture Mapping (PTM), invented in 2001 by Hewlett-Packard researcher Tom Malzbender [10], is a group of technologies for surface characterisation. According to Cultural Heritage Imaging (CHI), RTI is a computational photography tool that captures surface shape and colour and represents 3D reflectance properties of objects. It is an interactive re-lighting technique, further enhanced by mathematical transformations of the subject's surface shape and colour attributes [11].

Polynomial Texture Maps (PTMs) and RTIs can be created by the dome method or the Highlight-based method. Highlight RTI captures a series of raking light images of a static object, accompanied with one or two glossy balls with a static digital camera at constant exposure. The necessary equipment includes a digital SLR camera, a tripod, a light source and a glossy sphere, whose dimension is relative to the size of the object under examination. The accurate execution of the procedure, as described in detail in the Guide to Highlight Image capture [12], assures the successful completion of data acquisition. A typical scene set up for Highlight RTI data capture is presented in Figure 1.

The data processing methodology uses the RTI builder software, developed by University of


*Figure 1. Highlight RTI data capture scene.*

Minho in collaboration with CHI [13]. In case of Highlight RTI, images are loaded and saved, the sphere is selected and added by the user, and then the program executes sphere and highlight detection. Finally, the PTM or the Hemispherical Harmonics (HSH) fitter completes fitting) and results in artefacts visualised in polynomial texture map or reflectance transformation imaging format (*.ptm or *.rti), using either the polynomial texture map, developed by HP researchers [14], or the hemispherical harmonics fitter, developed at the University of California, in collaboration with CHI and T. Malzbender [13].

The other available option for RTI visualization is the dome method (Figure 2). In the case of dome RTI, data capture and processing is different because each dome has a pre-build lighting position file. There is no need to add spheres in the scene in data acquisition stage. During processing the builder uses the pre-build lighting position file and continues with fitting. More details can be found in the guide to highlight image processing, provided by CHI [13] and in the Hewlett Packard website [14]. The dome method provides automatisation, decreases time for capture - processing, and leads to better, more precise results while the highlight method is able to capture data regardless of the size of the objects, without any special instrumentation. A compromise between these two methods is the use of rotation rings or mechanical arms for the automatic moving of light (Figure 3).

PTM and RTI files can be viewed via specialized software. The RTI viewer (ISTI-CNR/CHI RTIViewer) (Figure 4A) is compatible with both .ptm and .rti files, while the PTM viewer (HP Labs PTM Viewer) (Figure 4) supports only .ptm files. Both programs enable interactive manipulation of the lighting position and enhancement of the final outcomes through different rendering modes. More details on viewers are provided by Cultural Heritage Imaging Guide to RTI Viewer and [15] and the Hewlett Packard website [14]. The technique contributes significantly in analysis, conservation and representation [16]. Microscopic RTI, using the microscopic highlight or the minidome method, offers interesting results leading to its broader application in the cultural heritage sector and, particularly, in conservation practice [17].

One of the most in depth analysis of RTI in numismatics is the study of coins from the Hospice of the Grand St. Bernard [9]. Not only was the superiority of PTMs over traditional documentation

Figure 2. RTI data capture, minidome.

Figure 3. RTI data capture, mechanical arm.

methodologies proved but also its significance in numismatic studies, communication and dissemination was discussed. Also the Diniacopoulos Collection coins RTI workshop, held in the departments of Classics and Conservation of Queen's University (RTIiCAN), Kingston, Canada in 2011, included coins from the Hellenistic to the Byzantine period [18]. Promising for the future of numismatics research is the Selby hoard project of the University of Southampton [19, 20].

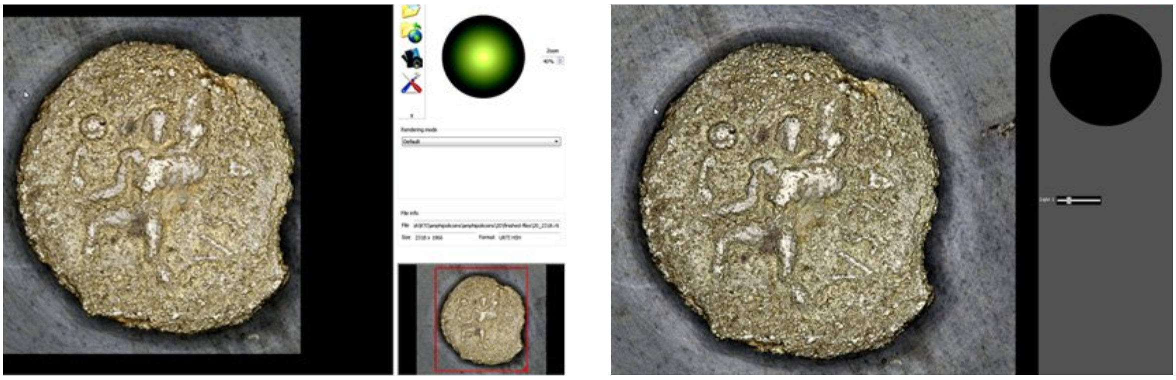

*Figure 4. Snapshots of the RTI viewer (left) and PTM viewer (right).*

Although the RTI community is increasing in number as well as in expertise, the application of RTI is limited to representations after conservation operations, without taking into consideration previous stages of its biography and 'non-static' nature of artefacts.

## Selection of Study Set

The 25 ancient a roman coins used for the purposes of the present study are lacking provenance information. These coins were selected for further investigation in an attempt to include coins that presented interesting surface phenomena and form a representative sample of the whole collection's condition. The cleaning operations and the experimental dome and highlight RTI tests using macroscopic means were carried out in the conservation laboratory of the Archaeological Museum of Amphipolis in Serres, Macedonia, Greece.

## Results and Discussion

This project resulted in 50 .ptm and .rti files which visualise coins pre-, during and post-cleaning operations. However, for the purposes of the present paper, only few characteristic examples will be presented to demonstrate the efficacy and the limitations of the technique. The following examples aim to describe the surface effects seen on the selected coins and to outline RTI contribution.

RTI's ability to emphasize surface variation proved to be extremely important for coin identification, even in cases of minor low relief details and/or highly corroded coins. The technique proved particularly interesting in cases of unidentified coins before conservation treatment such as the one shown in Figure 5. After cleaning, the human standing figure in the copper alloy coin becomes discernible (Figure 5D), although the coin surface is covered by corrosion products.

RTI not only assists identification and dating but also enhances examination and condition reporting. For example, it can emphasize surface effects due to conservation treatment. A silver roman imperatorial denarius of Julius Caesar minted in North Africa in 47–46 BC was chemically cleaned prior to acquisition by the Amphipolis Museum (Figure 6). As a result, it presents a stripped, porous, rough surface. Moreover, the scene represented on the reverse, Aeneas advancing to front,

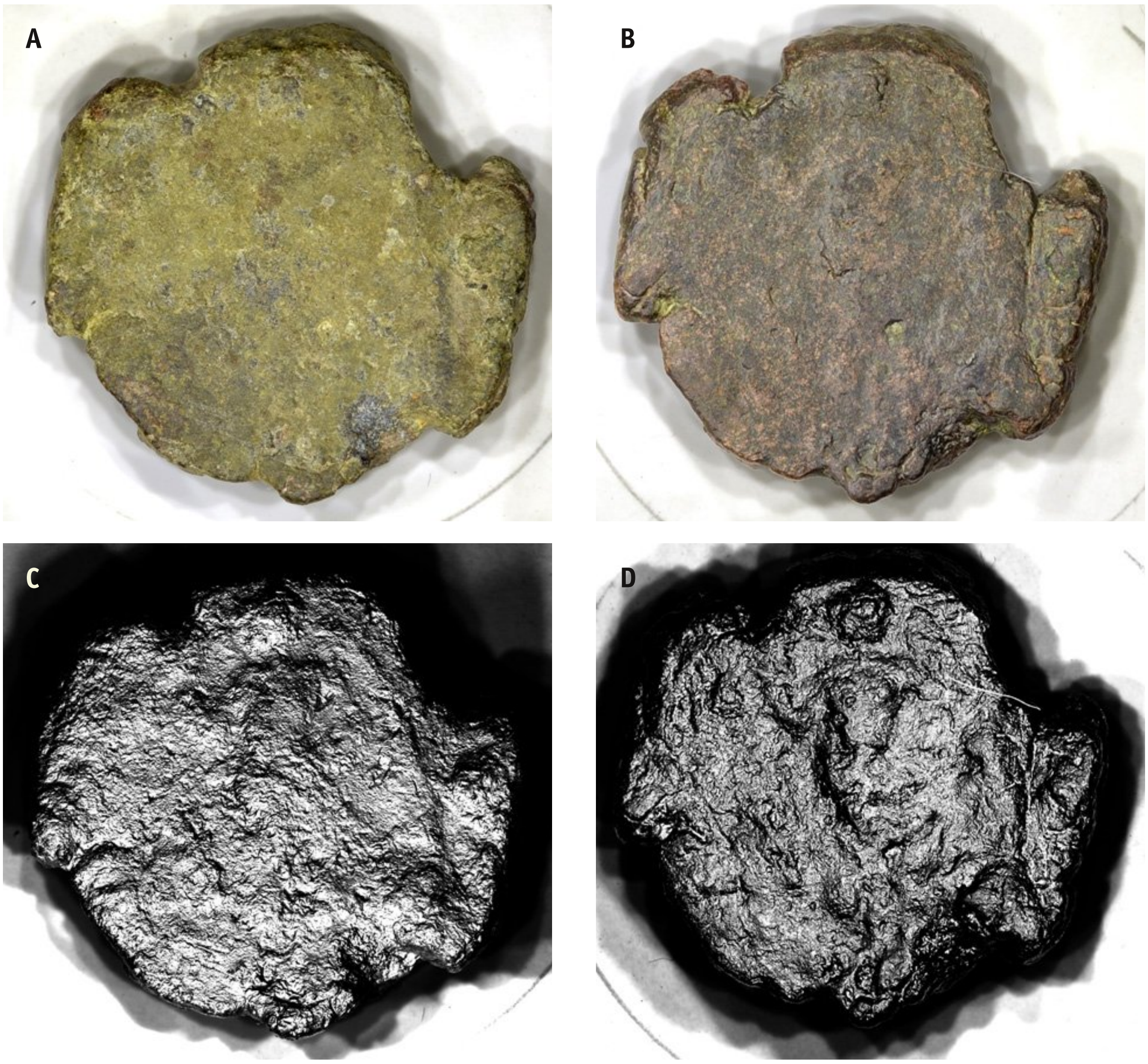


*Figure 5. Human figure representation on copper alloy coin (unidentifiable, Ø 18 mm): digital image before (5A) and after (5B) mechanical cleaning; and RTI visualizations in specular enhancement mode before (5C) and after (5D) mechanical cleaning (right).*

holding Palladium in the palm of his right hand and carrying his father Anchises on his left shoulder, as well as the legend "CAESAR" is hardly legible. The legend and the scene appear more vivid in the RTI snapshots than in digital image (Figure 6).

Also, surface effects such as corrosion, pitted surface, scratches, depositions and surface loss can be easily documented using RTI (Figures 7 and 8). But apart from condition reporting, a complete conservation record should narrate the objects biography or "life cycle", referred as 'treatment history' by Scott [7]. Taking into consideration that RTI viewing is comparable to the original artefact examination experience, the object visualization in relation to time and change before, after and during conservation intervention is recommended. This approach befits archaeological and conservation ethics and succeeds in capturing the objects "non-static" nature [21]. For example, the RTI visualization of

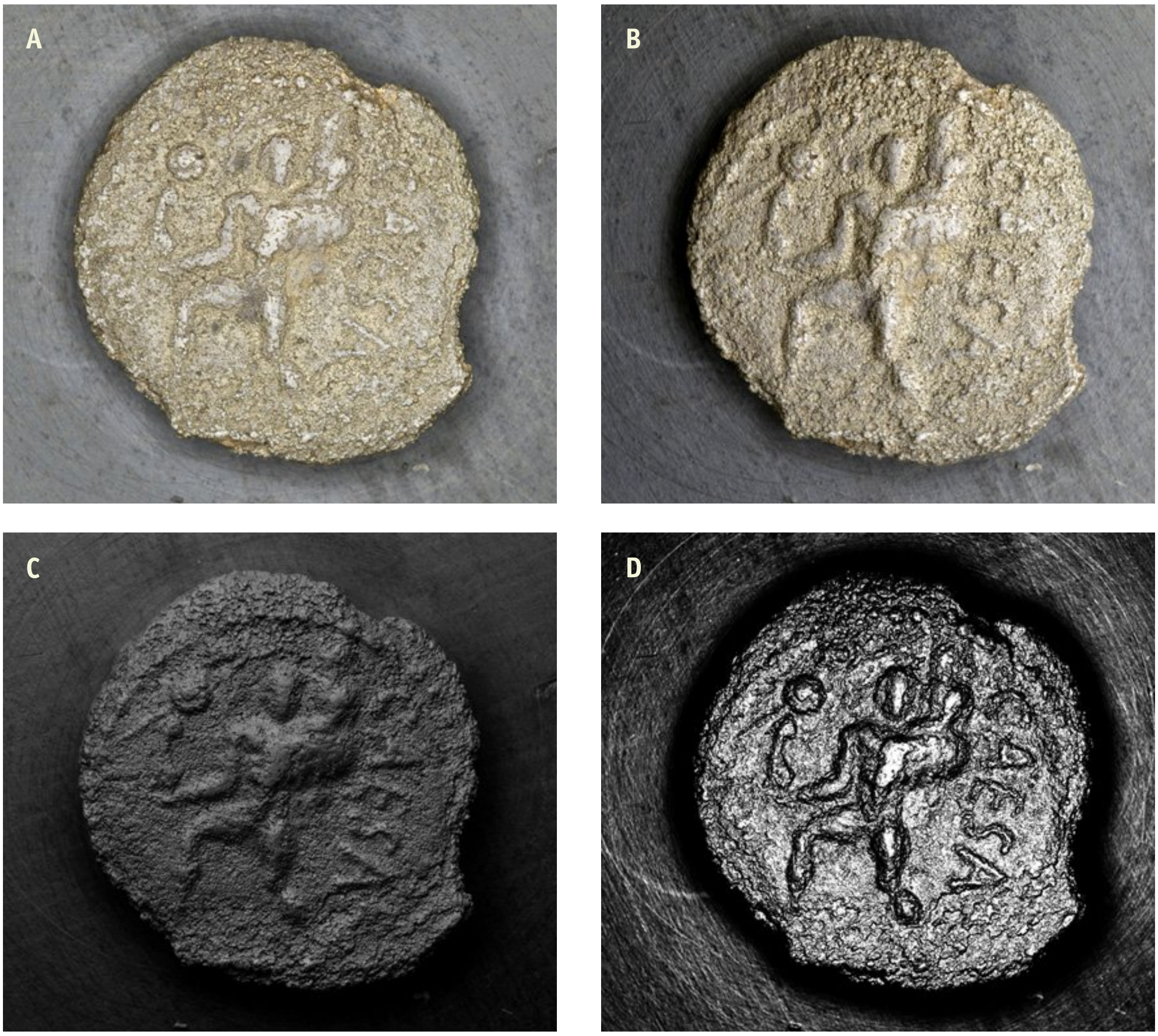


*Figure 6. Silver roman imperatorial denarius of Julius Caesar, CAESAR /Aeneas advancing to front, holding Palladium in palm of right hand and carrying father Anchises on left shoulder (Ø 19 mm): digital image (A) and RTI visualization in default (B) and specular enhancement mode (C, D).*

a copper alloy coin before, during and after conservation (Figure 9) captures the coin's "museum life", an inseparable part of its biography, or it can be used as means for cleaning monitoring. The copper alloy coin representing Salus standing right, holding out a patera in her left hand to feed a snake held in her right arm (Figure 10) required partial cleaning. RTI visualizations of the coin before cleaning documented the state of conservation while those visualizations executed after cleaning can be used for the evaluation of success of the conservation operation. The relatively smooth surface obtained indicates that no further action was required, neither for preservation, identification or aesthetic reasons.

The conservation process may lead to interesting conclusions about the various aspects of the coin under examination such as its manufacture and use. For example, it is known that surface cracking is strongly connected to minting. According to the bibliography, radial cracking indicates


*Figure 7. Silver coin not identified, possibly denarious of the family of Repousias (Ø 17 mm): digital image (A) and RTI visualizations in specular enhancement rendering mode (B, C, D).*

*Figure 8. Coin (Ø 17 mm): digital image (left) and RTI visualization in specular enhancement mode (right).*

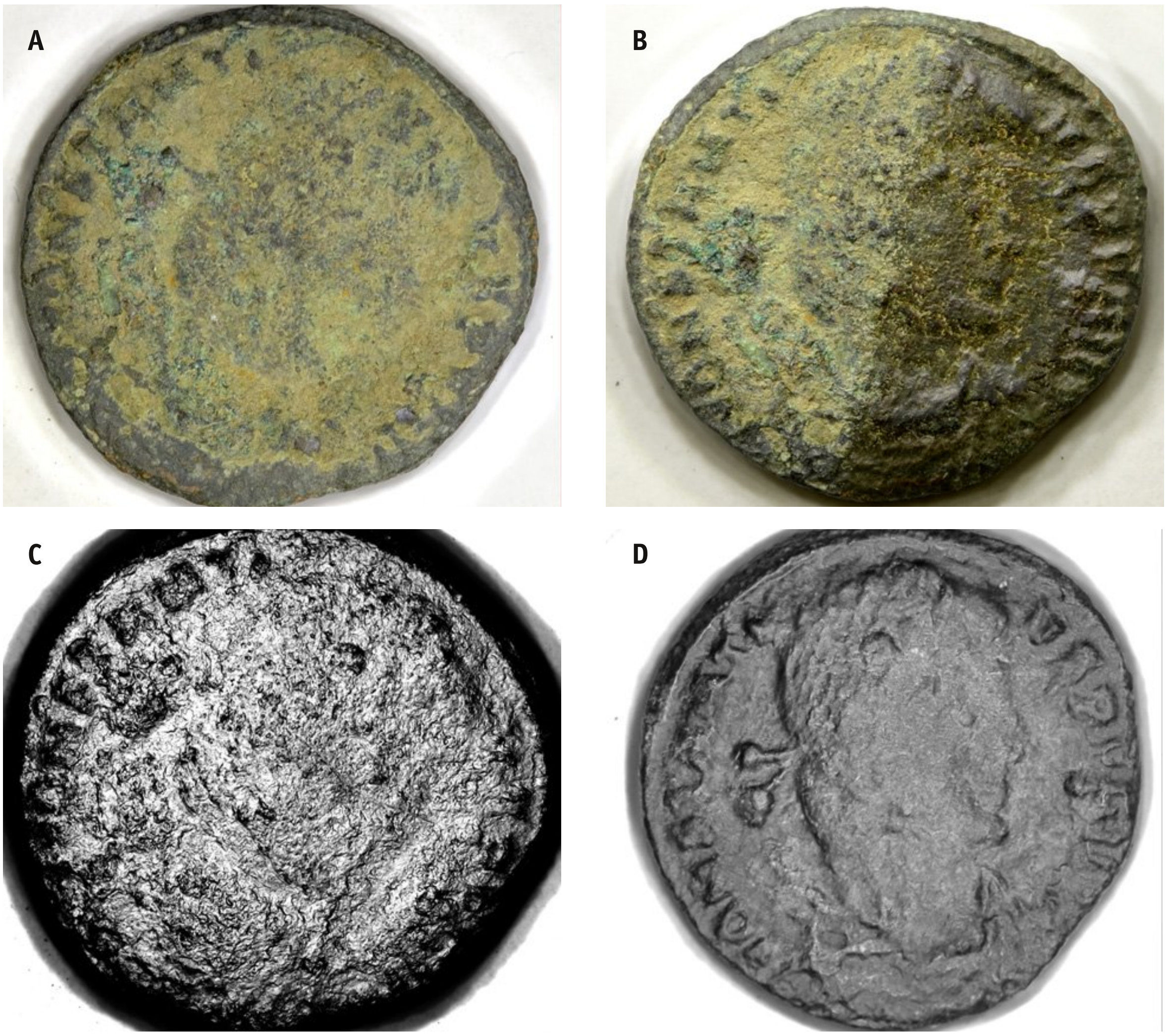

*Figure 9. Copper alloy coin, obverse, male bust (Ø 22 mm): digital images before (A) and during (B) conservation and RTI visualizations before (C) and after (D) conservation.*

coins hammered to shape, while crack irregularities, such as those on Figure 11, are considered a result of striking [22]. RTI ability to underline surface variations can be helpful to distinguish cracks among other defects, study their form and potentially reach conclusions for coins manufacture.

As far as the protection and the stability of artefacts are concerned, RTI visualization is an action of high respect towards the remnants of the past. It can play a crucial role as a preventive conservation measure as RTI limits the contact with the original material considerably [17]. According to Hoge, minimal handling of coins is recommended since contact with human skin encourages corrosion due to the presence of fatty acids from the skin and humidity from human breath, as well as mishandling, an action which may result in physical damage [23].

## RTI Critique

RTI is a powerful technique. It takes digital photography to the next level of analysis. A comparison


A
B
C
D
E
F
G
H

*Figure 11. Copper alloy (unidentifiable, Ø 15 mm): digital image (left) and RTI visualization (right).*

of the outcomes of RTI and digital photography methodologies demonstrate the impressing capabilities of RTI. No single captured image can demonstrate the characteristic features of archaeological objects, especially coins, such as three-dimensionality and geometric complexity, in addition to the surface topography of deteriorated material. Also, specular enhancement capability of RTI viewers can be compared to specular axial or oblique illumination imaging. Moreover, the ability to change the specular parameters in the viewer enables the enhanced recording and examination. RTI combines successfully raking and specular illumination imaging techniques. Not only has it record surface anomalies, traditionally captured by specular illumination, but also the surface texture, usually documented with RTI. The latter is flexible enough to implement different photographic set ups according to the needs of the photographed object. Consequently, RTI is a more holistic approach than other techniques.

RTI is an affordable technique for documentation, monitoring and examination. The economic cost does not raise a barrier at all because of the standard commercial photographic equipment needed for data acquisition and the free software employed in processing and viewing.

There is no doubt that the time and expertise needed for the execution of RTI is not comparable to traditional techniques such as regular digital photography. RTI data capture and processing is more laborious and time consuming. Although the RTI process is rather simple, familiarising with the technique requires time. Also worth mentioning is that RTI training is not included in the programme of the vast majority of educational institutions as the other photographic techniques (multispectral imaging, raking light etc.), which are well disseminated. However, the time needed for data capture and processing as well as for training is worthy, as RTI encapsulates in a single file the data provided by other imaging methodologies.

*Previous page:*
*Figure 10. Copper alloy coin, SALUSAVGG/ Salus standing right, holding out a patera in her left hand to feed a snake held in her right (Ø 22 mm): digital image before (A) and after (B) treatment, and RTI visualizations before (C, D, E) and after (F, G, H) treatment.*

RTI visualisations of artefacts can be furthered processed making use of the various rendering modes available within the viewers' software. The result of such processing may be visualizations that present features different to the common digital images. Although this phenomenon is the power of the technique it does not come without its limitations. It is recommended for RTI users to address critically features which appear strange based on previous knowledge about artefacts, materials' optical properties, damage or alteration. The interpretation of such features requires special attention and, if possible, implementation of other techniques to avoid misleading conclusions about the artefact under examination. It is obvious that the wise use of the technique is an imperative need.

There are no restrictions in the manipulation of RTI files and every user can make its own discoveries, exploring the various components of artefacts. The crucial point in the whole process is to keep metadata for the visualizations produced by the software, including the *ptm and *rti general files and the single renderings (snapshots) from each lighting condition under each rendering mode employed. This approach is the logical and sophisticated manner of experiencing RTIs. If the metadata process is overlooked, the visualised digital artefact will display neither a useful nor a trustworthy version of the original, with limited research potential for the scientific community.

## Conclusions

The results indicated that RTI not only assists coin identification but also enables advanced conservation documentation and monitoring of cleaning operations. Moreover, RTI's use in the field of preventive conservation, as well as its significance for providing access to cultural heritage collections is advantageous, in particular in the case of coins, regarding problems of small size and low relief detail.

Thanks to the recent developments of RTI technology, the application of such an advanced digital technique is not restricted to major museums and research institutions but can be part of the everyday mainstream conservation activities. It is obviously of great importance for the conservators to be aware of the potential advantages and limitations of new technological developments.

Considering the above, the conservation community can take advantage of the new possibilities for enhanced coins identification, examination and documentation. In the future computer vision and other computational photography techniques, such as algorithmic rendering, will provide even more powerful techniques for lab recording.

Questions arise whether the development of new digital tools may affect our attitude towards remedial conservation. In this sense preventive conservation measures would assure the safeguarding of material integrity, while coins visualised in *ptm and *rti form would provide an easily accessible and legible digital analogue.

## Acknowledgments

The authors are grateful to Dr. Graeme Earl of the Archaeological Computing Research Group, University of Southampton for his continued advice and support, as well as Aikaterini Peristeri, director of the KH' Ephorate of Classical and Prehistoric Antiquities, Hellenic Ministry of Culture for providing access to the archaeological material.

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**No. 25, Spring 2013**

**ISSN:** 1646-9283

**Registration Number**
125248
Entidade Reguladora
para a Comunicação Social

**Property**
e-conservationline, Rui Bordalo

**Periodicity**
Biannual

**Cover**
The Homer Telephone Exchange
Pratt Museum in Homer, Alaska, USA
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