Telling the Story of Ancient Coins by Means of Interactive RTI Images Visualization

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Abstract:
We present a system to provide an enhanced access of ordinary people to a collection of ancient coins, preserved in the National Museum of San Matteo in Pisa (Italy). Those coins have been digitized to produce RTI representations and are presented to museum visitors together with data telling their story.

The interactive presentation system, designed to be deployed either by a museum kiosk or by a web site, is composed of two integrated sections: a brief introduction to the different subsets of coins; an interactive RTI viewer. The coins are organized in different subsets to better present them to a public of inexperienced visitors. The viewer supports the interaction with the RTI image through a set of functionalities: changing the light direction; zooming; panning over the image; flipping the coin; visualizing hot spots, which link specific areas on the coin with descriptive HTML hypertext.

Keywords:
RTI Images, Ancient Coins, Interactive Kiosk, WebGL, SpiderGL

1. Introduction

Reflectance Transformation Imaging (RTI) is a computational photography method that, stating from a set of images taken from a single view under varying lighting conditions, encodes the subject's surface shape and colour to enable the interactive re-lighting of the subject from any direction. RTI encodes this redundant data, the same scene sampled under many different lighting conditions, in a compact way, using view-dependent per-pixel reflectance functions.

The virtual examination and study of Cultural Heritage artefacts is taking advantage from the use of the RTI techniques. In this field the way light interacts with the object is very important because the characteristics of the material, reflectance behaviour, and texture offer major perceptual and cognitive hints for the study of a Cultural Heritage object. In many cases the ability to interactively play with the light is often more useful than the manipulation of an accurately sampled 3D shape, that is hardly able to capture all the interesting aspects of the artwork. Furthermore, there are several advantages of RTI technologies compared to 3D scanning techniques: RTI techniques use inexpensive and widely available hardware (in many cases, just a digital camera and light), scale well to both large and very small objects, and are able to easily achieve a sampling density and a precision that most current 3D scanners are unable to reach, even under optimal acquisition conditions. For those reasons, RTI techniques are widely used in the Cultural Heritage field for documentation tools and to support detailed visual analysis.

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RTI techniques were designed to support easy documentation and inspection of Cultural Heritage artworks, giving a precious instrument to the specialists in the analysis and interpretation process. The recent advances of the web visualization instruments are increasing our capability to disseminate data and to support remote visual inspection of both scholars and ordinary public.

We present an interactive kiosk for the interactive presentation and virtual inspection of coins collection using HTML 5 technology and RTI images; the specific test case, the coin collection of the National Museum of San Matteo in Pisa, gives us the opportunity to present the underlying technology in the framework of a concrete and practical project.

2. State of Art on RTI Acquisition and Visualization

The first RTI image format was introduced in 2001 (Malzbender, Gelb, and Wolters 2001), with the Polynomial Texture Maps (PTM). This image encodes the per-pixel reflectance function using a biquadratic polynomial. Already in this original work, the PTMs are presented as a powerful tool to improve the study of ancient writings and inscriptions. Authors proposed two contrast enhancement methods which allow improving the readability of the ancient inscription by mathematical manipulation of the biquadratic polynomial. A new encoding for RTI data was proposed in 2009 (Gunawardane et al. 2009), the Hemispherical Harmonics Map. This new format uses a linear combination of the first nine hemispherical harmonics for the reflectance function, enabling a higher rendering quality due to the better sampling properties of the new per-pixel function.

In the last 10 year RTIs were employed in several applications. They were used in Palaeontology, to provide noticeable improvement in imaging of low colour contrast, like high relief fossils (Hammer et al. 2002). The application of PTM method on ancient stone tools revealed fine details of concoidal knapping fractures, use scarring and stone grain (Mudge et al. 2006). A joint work done by National Gallery and Tate Gallery of London showed that PTMs provided additional information about the surface textures of oil paintings (Padfield, Saunders, and Malzbender 2005). Cuneiform tablets were analyzed using both 2D (PTM) and 3D (structured light scanner) information; the PTMs were texture mapped on the model, and a special 3D viewer was created (Mudge et al. 2006). The application of PTMs and scanning techniques on a large numismatic collection permitted the creation of a more complete documentation than the traditional photographic methods and the communication of this information with ease through digital media (Mudge et al., 2005). PTMs were used to study the Antikythera mechanism, an ancient mechanical computer designed to calculate astronomical positions (Freeth et al. 2006). Here, the analysis of the different fragments using PTMs increased the readability of the inscriptions, allowing a more complete understanding of the mechanism operation. The potential and the advantages of the application of the RTI images in the archaeological context was analyzed in (Earl, Martinez, and Malzbender 2010; Earl et al. 2010), especially in the field of the conservation, analysis of the material and representation of the archaeological data.

Improved methods were proposed for the acquisition of RTI images. A method to acquire the RTI of large object, using a single moveable light and an acquisition plan without the employ of a light dome, was presented in (Dellepiane et al. 2006). An automatic method for RTI generation based on the tracking of the highlight position of the light source on glossy spheres was proposed in (Barbosa, Sobral, and Proença 2007). In this way the user is free to move a single light source around the object and, after the acquisition, he can use an automatic tool to estimate the encoded light direction of each photo.

Advanced shading enhancement techniques were proposed in (Palma et al. 2010). The authors proposed a set of enhancement operators for RTI images that improve the perception of details, features, and shapes depicted in the image and provide better and more flexible visual inspection capabilities.

3. The San Matteo Coins Project

The San Matteo coins project started from the request of the curators of the National Museum of San Matteo in Pisa to allow presenting the ancient coins collection of the museum in an innovative way, to better capture the interest of the visitors and to give them enhanced information. The attention of the museum curator towards the coin collection is due to the current way to expose and present it at the public. A coin is a very small artwork, which in a standard museum exposition is presented to the public from a distance (typically at least 50cm far from the observer eyes). This distance does not allow to the visitors to note some small and interesting details on the legend or on bas-relief and, moreover, the coin is usually visible only from one side. Furthermore, coins have a lot of hidden knowledge that is difficult to transfer to the visitors in an easy, effective and understandable manner.

The main challenges of this project were:

- to allow the virtual manipulation of the coins to inspect them in detail;
- to bring some of the hidden knowledge of the coins to the ordinary public in an easy and understandable way.

We proposed the design and implementation of an interactive kiosk to allow the presentation and the virtual inspection of the coins collection. The kiosk must be easy and intuitive to use for the ordinary public of the museum, and it must allow the real-time manipulation of the coin with a set of basic operations like zooming, panning, flipping the coin, changing of the light direction. Finally the kiosk must tell the story of the coins using multimedia data, with a combination of text, images and videos. For this last purpose the coins are organized in several subsets, each one characterized by a feature that can be the historical collection to which the coins belong to or a common thematic subject (for example the coin of a specific geographic area or epoch). In addition, we put on the surface of the coins some hot-spots that contain additional multimedia information useful to better understand the most important and interesting details depicted on the coin engraved decorations.

The management of the virtual inspection of the coins is one of the most important aspects in the design of the kiosk. Several scientific researches (Ramachandran 1988; Adelson and Pentland 1996) proved that the human brain is able to infer more cognitive data from the dynamic reflection and shading of an object. Then it is a fundamental requirement to give to the user the possibility to rotate the coin under, at least, a directional illumination. This means that we need a virtual representation of the coin that can simulate the illumination effects in real-time and in an accurate way, in order to obtain a photo-realistic rendering. In the choice of this virtual representation we have to pay attention because typically the production of a photo-realistic rendering of a coin is extremely complex, due to the reflection effects of the different types of materials. For example in the museum collection we have both high reflective and specular gold coins, and bronze coins, that are more opaque and present on their surface different kind of patinas and degradation processes that alter their appearance (Fig. 1).

There are two possible options for the virtual representation of the coin: a complete 3D model or a RTI image. The creation of a 3D model requires to acquire both the 3D geometry and the surface appearance. This task could be quite complex because scanning coins introduces several problems and drawbacks. The acquisition of the geometry can present problems with the scanning of the coin's border, that can be very thin, and the right alignment of the two sides of the coin. The acquisition of the reflectance must be done in a following step with special setups to sample in an accurate way its dimensionality. Even if several solutions have been proposed for the acquisition of the surface appearance of real object, all ones have some drawbacks. They require a very intensive data acquisition, that must sample in accurate way both the light and the view directions, and complex reflectance models that, due to the assumptions on the reflection effects that we want to capture, are not able to reproduce all type of materials. Finally, the processing of the acquired data for the creation of the final 3D model is time consuming and the manipulation of a 3D model is still more complex to understand and control for the user.

On the other hand, RTI techniques produce a 2D representation of each coin that encodes both the surface normal and the appearance in a single image. This image can be dynamically relighted by the user reproducing the illumination-dependent effects of the surface with a higher quality and a higher resolution that is not usually provided by 3D scanned model. The acquisition and processing step are cheaper than 3D scanning and the final representation simplify the interaction because the user is more accustomed to interact with an image than with a 3D model. For these reasons our choice was to adapt RTI images for the San Matteo kiosk.

4. Acquisition and Processing of RTI data

The first step of the project was the acquisition and the generation of the RTI images. For the acquisition the museum curator selected a subset of 41 coins from the museum's collection, following value and storytelling criteria. The coins cover different epochs, from the Roman Empire to the Grand Duchy of Tuscany (XVI –XIX centuries).

For the digitalization we used a minidome designed by the University of Leuven (Willems et al. 2005)cuneiform tablets, either manually, by moving lights around the tablet to maximize readability, or by studying photographs (or drawn copies. The dome is composed by 4 shells that can easily assemble and disassemble to simplify the transport. It has 260 white LEDs and an overhead CCD camera, and it is computer controlled to allow a completely automatic acquisition (Fig. 2). For each coin the acquisition takes about 10 minutes, required to shot and store 520 photos (260 photos for each side). The data was recorded with 3 different integration times, to provide the necessary dynamic range for HDRI imaging and further analysis. Different sets of lenses and macro rings have been used to cope with the variety of sizes in coins. All the coins were digitalized in a single working day. It was made on site in the museum thanks to the features of the used light dome (it can be dismounted and transported easily). The acquisition phase was done by staff of the University of Leuven, but it is quite easy to do even for a person without any specific expertise in this field. In the specific the hardware setup requires only to mount the shell and the camera and to put the coins in the middle of the dome, while the software tuning needs only to set the exposure time in an interactive way with visual feedback.

The processing of the acquired raw data to produce the final RTI image involved 3 steps:

- the transformation of the raw image taken with the minidome from the Bayer Pattern to a RGB format;

Figure 1. *Two example of coins inserted in the kiosk: (Left) a Roman bronze coin; (Right) a modern gold coin.*

- the generation of an RTI images for each coin side using the tools provided by Cultural Heritage Imaging corporation (Cultural Heritage Imaging 2012);

- the construction of a multiresolution streamable RTI format that permits the asynchronous loading of the image, allowing to the user to interact immediately with the coin without the awaiting of the complete loading of the data.

For the generation of the RTI images we chose the HSH format because it guarantees a better reproduction of the specular reflection with results that are more photorealistic with respect to a PTM, as showed in (Mudge et al. 2008).

For the construction of the multiresolution format, we subdivided the RTI image in nine layers, one layer for each HSH coefficient (Fig. 3). The i-th layer contains the i-th coefficient of the three RGB colour channels. For each layer we created a multiresolution tree and we cut each level of the tree in tiles using a quad-tree structure (Fig. 4). Finally we saved each tile in a different PNG image. This means that to visualize a specific pixel we need to load the nine PNG images that contain the HSH coefficients of the pixel. We chose PNG format because it guarantees a lossless compression that reduces the amount of data to transfer from the server to the client without to lose any information needed for the photorealistic rendering. The advantage of multiresolution streamable format is the out-of-core loading of the tiles making immediately available at least some low resolution data, to allow to start quite instantaneously the user interaction with the coin. In the specific at the beginning of the loading the user interacts with a low resolution version of the coin, which is progressively refined as soon as the higher resolution data are loaded. The loading of the tiles at the different resolutions is guided by the zoom and pan operation of the user.

The generation of the RTI images took about 24 hours of totally automatic processing, without user intervention.

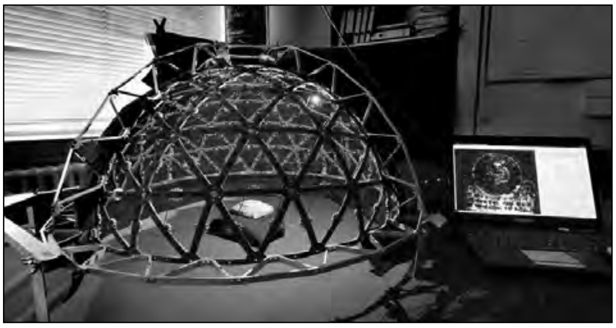

Figure 2. *Minidome from the University of Leuven used for the RTI acquisition.*

Figure 3. *Decomposition of the nine layers that compose the HSH image format.*

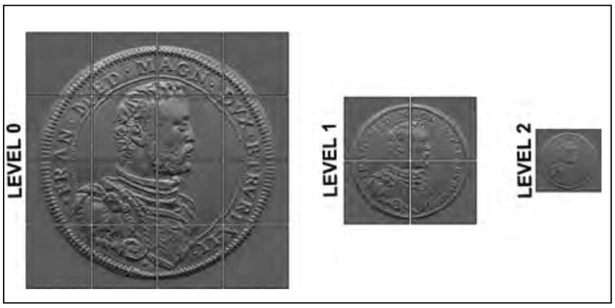

Figure 4. *Quad-tree encoding of the RTI image.*

5. The San Matteo Kiosk

The kiosk is composed by two integrated sections. The first section allows to introduce and present to the user the different subset of coins. The second section permits the interactive RTI visualization. The kiosk has been implemented by using the Community Presenter, a tool developed for designing informative kiosks in the 3DCOFORM project. This also demonstrated the flexibility of the tool that has been designed for managing 3D data and has been extended to manage an innovative 2D medium such as the RTI images.

The main features of the kiosk are:

- the organization of the coins in categories and the presentation of these categories with multimedia data;
- the virtual inspection of the coin by RTI manipulation. We associate to each coin a general presentation and some hot-spots, that are located on selected areas on the surface of the coin to tell the most important and significant details;
- the possibility to run the kiosk on a web site or on a touch screen system (an interactive installation inside the museum) thanks to the technologies used for the development: HTML and JavaScript for the general structure of the kiosk and for the presentation of multimedia data; WebGL and SpiderGL for the RTI visualization.

WebGL (Khronos Group 2009) is a library that extends the capability of JavaScript to allow the interactive generation of 3D content within any compatible web browser (Chrome, Firefox, Opera, Safari). The main advantage of WebGL, with respect to the previous solutions for the integration of 3D content in the web, is the absence of external plug-ins to be installed, because WebGL is a build in feature of modern web browsers. SpiderGL (Di Benedetto et al. 2010) is a computer graphics JavaScript library that provides a set of data structures and algorithms to simplify the development of a WebGL application. It is composed by a number of modules that allow to define and manipulate shapes, to import 3D models in several formats, to handle asynchronous data loading and to manage the user interaction. The use of WebGL and SpiderGL allows to customize the pipeline of the Graphics Processor Unit directly from the web browser with specialized shaders. The custom shaders permit to have a complete interaction with the RTI image changing even the light direction in real time. This kind of interaction is not possible with a simple HTML viewer for 2D images because without WebGL we does not have the possibility to change the rendering of the object dynamically and in real-time.

The presentation section is characterized by a HTML template with a JavaScript engine that allows to load the multimedia content to visualize in the kiosk. The multimedia content is organized in XML files. For each category we store the multimedia HTML data and the list of its coins, while for each coin we store the general description and the position and the content of the hot-spots. The JavaScript engine loads dynamically the content from the XML files according the user choice and interaction.

The Figures 5-8 show some screenshots of the kiosk. Entering from the cover page (Fig. 5 - top left) the user has a presentation page of the project (Fig. 5 - top right). On the left there is a menu that allows to navigate among the different pages of the first section and to access directly the RTI viewer. In the middle there is a short description of the project. The items in the menu allow the access to the different subsets of coins. The subsets are subdivided into two categories: the historical collections (Figure 5 - bottom left) and the thematic subject (Figure 5 - bottom right). The San Matteo Museum's coins belong to three different historical collections:

- the Moise Supino's collection, dealer of Pisa in the 19th century that gave his coin collection to the museum;
- the Angiolo Franceschi's collection, archbishop of Pisa in the 18th century;
- the collection of coins findings, that contains the small treasures discovers in Pisa and surroundings in the 20th century.
- The thematic subjects are four:
- the coinage techniques, that explores the different methods for the production of the coins;
- the coins of the Tuscany, that presents the coins of the Tuscany cities in the different epoch;
- the iconography subject, that analyzes the changes in the representation of the main characters of the bas-relief in the different coins;
- the value of the coins, topic dedicated to the understanding of the economic value of the coins.

By selecting a subset, the user can read additional information about it (Fig. 6). The multimedia presentation content is showed in the middle of the page. The content is organized in several subsections that can be navigated and consulted with the arrows in the bottom of the page. On the left there is a scrollable bar with the thumbnail and the name of the coins in the subset. By clicking on a coin in this bar the user can open the visualization of the relative RTI image. In the page of RTI images (Figure 7) there is the RTI viewer in the middle, a general description of the coin on the left and the scrollable bar on the right. Using this bar the user can switch very quickly on other coins of the current subset. In the RTI viewer we have a title bar on the top with the name of the coins and the name of the subset used to access it, and a tool bar on the bottom that allows the manipulation of the images. The user can change the light direction, pan the image, zoom in and zoom out, flip the coin to see the other side, enable the visualization of the hot-spots. By clicking on a hot-spot the user can display the relative multimedia content on the left side of the page (Fig. 8). The visualization of the hot-spot's content is preceded by an automatic zoom animation on the detail associated to the hot-spot to better highlight it. The arrows in the bottom of the dialog allow to scroll among the images associated with the hot-spot.

The interactive kiosk will be installed at the end of 2012 at the National Museum of San Matteo in Pisa. The installation setup is composed by a 24-inch multi-touch screen, used for the user input and visualization, paired by a bigger screen set on the side that shows the same content of the touch screen, allowing a clean vision for the other visitors that don't interact directly with the kiosk.

6. Conclusions

We have presented the design and the implementation of an interactive kiosk for the visualization and inspection of a coins collection using multimedia data and RTI images. The kiosk is designed to be easy and intuitive to use for the ordinary public of the museum, and to transfer a part of the knowledge of the coins using multimedia data, with a combination of text, images and videos. For this purpose the coins are subdivided in several subsets, to better present them according different criterions and aspects, and each coin is complemented by a set of hot-spots useful to better understand the most important and interesting details depicted on the engrave decoration. The overall methodology was successful since:

- coins are 3D, but usually most of the interest is in their front and back faces, rather than on the side;

- visual inspection of coins is performed usually by changing the light and gathering 3D information from the dynamically change of the reflection and shadows; this is exactly what is supported (at high quality) by the interactive inspection of the RTI medium, more faithfully than what is possible with the interactive rendering of 3D models;

- RTI 2D acquisition is faster and more automatic than the corresponding 3D acquisition, thus results in savings for the digitization phase;

- finally, we have showed how to include also this representation type in a tool for interactive presentation of 3D models (the Community Presenter), extending its capabilities and flexibility.

Figure 5. *(Top-left) Cover page. (Top-right) Presentation page. (Bottom-left) The collections. (Bottom-right) The thematic subject.*

Figure 6. *Category content.*

Figure 7. *RTI viewer: (Top-left) starting page; (Top-right) activation of the hot-spots; (Bottom-left) coin detail; (Bottom-right) coin detail with a different light direction.*

Figure 8. *Visualization of the hot-spot's content.*

To understand the real effectiveness of the current organization of the kiosk, we have implemented a data logging framework that allows to record the interaction of the users with the system in order to allow following analysis. From this analysis we will be able to evaluate different things, as the easiness of the interface, the relation of the user with the new RTI technology (time spent in the interactive manipulation session), simple statistics on the most viewed categories and coins, and so on.

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