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Digital Materiality with Enhanced Reflectance Transformation Imaging

Fornaro Peter, Bianco Andrea, Rosenthaler Lukas; Digital Humanities Lab, University of Basel; Basel, BS / Switzerland

Abstract

The Digital Humanities Lab is a research institute of the faculty of Humanities of the University of Basel. The research profile of the dhLab is centered around computer science, digital imaging, digital photography and the accessibility of digital objects in humanities research. The project Digital Materiality examines how new methods to describe the reflection of light on surfaces can be applied to art historical research. In the main focus are mosaics and early prints. Both types of artwork have a strong interaction with light. Unfortunately standard photographic approaches are not able to capture the dynamic component of the light-surface interdependence.

The technical part of the project focuses on improving RTI (Reflectance Transformation Imaging) techniques. By modifying the model accordingly to the requirements of art historical research, the digital reproduction shall be able to transport the relevant attributes of the original in the digital domain. The improvements take into account more sophisticated but still robust reflection models that allow the realistic visualization of diffuse and specular surfaces. The visualization is implemented in WebGL, to allow the integration of RTI in an web-based environment, especially Virtual Research Environments, VREs

Introduction

Images are a very important type of media for art communication and documentation. Photographs make the visual impression of objects accessible and they are a precise tool to capture the state of an original e.g. before and after a restoration. In the digital domain the access to reproductions of originals is even simpler. Digital images can be easily shared, disseminated and given access to. Besides access, today it is inevitable to digitize analogue images because of the unstoppable physical decay of the originals. Therefore digital images are already an important part of our cultural heritage and they account for a constitutive part of our contemporary multimedia output in social, scientific and economic ambits [1].

Photography has changed in the last years. The transition to the digital domain has not only brought a new standard in quality, it also opened new applications of computers and digital tools. Applying computer technology to digital images allows methods that go far beyond conventional photography. Computational photography is therefore a promising approach for a more comprehensive way to capture, communicate and disseminate digital art of any kind (reference [2] shows several examples).

Any artwork is a unique piece that only appears in its full richness as a original. However, in many cases access to such originals is limited. Most artwork, like for example paintings or analogue photographs, must be stored dry, dark and in cool environment. To overcome those limitations in access, digital photography is one way to capture the basic visual appearance of an original. Unfortunately many originals can not simply be digitized and represented by one or more images. Objects with complex surfaces topographies or reflection behavior need another technique to capture the important attributes of light-surface interaction. A promising method is Reflectance Transformation Imaging [3] [4]. RTI is a set of computational photographic methods that capture a subjects surface shape and color and enables the interactive relighting of the subject from any direction based on a mathematical model. The method was originally developed by HP-Labs [5]. Polynomial Texture Mapping (PTM) best describes the principal technique HP has followed. The reflection of light is in a first step captured by multiple photographs illuminated from different positions. In a second step a simple mathematical term, a polynomial of second order is fitted to the measured reflection for each pixel position. This approach is convenient from several points of view: Only little amount of hardware and software is required to acquire a PTM, stability and reproducibility are easy to guarantee because of a reliable fitting procedure and only relatively little knowledge to operate the tools is required. The major drawback of PTM are the limitations of the mathematical model that is applied. A second order polynomial is able to reproduce reflection of diffuse surfaces, also called a lambertian surface, realistic reproduction of gloss is not possible. A lambertian surface scatters the incoming light in such a way that the apparent brightness does not depend on the observer's point of view. Although the radiance of the surface depends on the angle between the normal and the illuminating source, following the lambertian cosine law, it does not depend on the angle between the normal and the observer; it has a uniform reflection. Differently, a glossy surface has a component of specular reflection. Specularity means, that light is reflected only in one direction, defined by the law of reflection (also called Snell law), a mirror shows a perfect specular reflection[6]. The limitation of he second order polynomial is crucial for the reproduction of many artworks like e.g. mosaics. A mosaic is basically constructed to interact with light and in most cases diffuse and glossy materials are placed on purpose to constitute the artwork in a specific manner. Another drawback is the required software to do RTI images [7]. Locally operated standalone software is state of the art. There are basic approaches to integrate an RTI viewer in web environments but because of the mentioned limitations of the modell such a solution is not able to reproduce objects made of diffuse and glossy materials properly. Therefore we are trying to improve RTI by the following means:

- Using a data-driven scientific approach to find a better model or an analytical representation to be able to reproduce, lambertian and glossy materials with as few parameters as possible.

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- Using WebGL, a common graphics library based on the well-known ”Open GL”, to render RTI images in a web-browser. Such a solution opens various new applications and the possibility for collaborative work.
- Embedding RTI in a Virtual Research Environments (VRE) for annotation and interlinkage of multiple originals stored in one or more repositories.

The first point takes into account two different processes:

- Acquired data and use RTI methodologies to distinguish between glossy and lambertian material in an arbitrary object.
- Modeling gloss reflectance behavior referring to art historian scholar's impressions; therefore the model must have adjustable parameters to allow the customization to the needs of the experts.

Experimental set-up

Hardware

Our experimental setup is a geo-dome structure (see figure 1) made of aluminum tubes, connected by CNC-machined aluminum joints, equipped with approximately 30 to 50 commercial photo flashes powered by a external high current power supply for short recharge times. The structure is approximately 190 cm in diameter and 95 cm in height. A high resolution digital SLR is mounted on the structure. The flashes are synchronized with the camera by a custom made bus-system with multiple decoders and a control unit. The bus-system to control the light allows to remotely address six different outputs per decoder that can control various types of light sources, e.g. VIS, UV or IR LEDs or lamps or flashes based on other technologies.
The light bus-system is a flexible approach and especially designed for the purpose of RTI capturing. The decoders are simply to wire by RJ45 compatible cables, they are fully addressable and each decoder can be configured to control the lamp at a specific duration and power of illumination. In addition it can be configured to automatically do interval triggering. For the application of RTI image capture the light system is triggered by the camera that is controlled by a remote capture software. That allows automatic image capture and data transfer to an appropriate storage system. The main advantages of this set up are reproducible and calibrated results that can be gained semi-automatic. Calibration is very important for RTI image data because of the importance of the exact knowledge of the position of the light source. If the system can be calibrated and the calibration information can be stored as technical meta information, larger assets of originals can be captured without much human interaction. Besides the light position, the light intensity, the light color and the distance of the target can be measured and taken into account. For experimental purposes the geo-dome is located in a dark room, assuring that no ambient light is affecting the measurements. These characteristics make the setup an ideal structure for examination and modification of basic principles of PTM. As a consequence it allows the study of light reflection on numerous types of surfaces. Due to the identical situation of each capture process, results of various originals can be compared and conclusions can be derived based on proper data. In addition a well documented and calibrated system is the key element for data sustainability. Only a reproducible, well-documented physical measurement process can lead to RTI image data of sustainable scientific value.
The structure has other positive features: It is stable and it can be moved and transported; the flashes provide a broad light spectra, have a high reproduciblility and can be operated with a short cycle time. The development of a smaller geo-dome set-up that is as lightweight as the one described in [3], [8] or [5] is currently under development at a professional studio and photo light company in Switzerland.

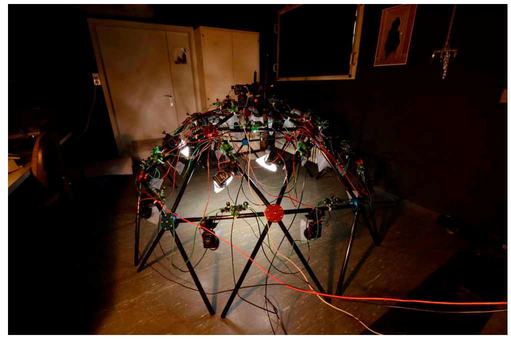

Figure 1. *The geo-dome structure*

Software

For simplicity and reliability, the software in our set-up is divided in three parts:

- Calibration and image elaboration: In this step already existing software is mainly used, a short list includes: CHI RTIBuilder [9] for the calibration of the lights direction; camera specific proprietary software for remote capture and Adobe Raw Converter® for image transformation.
- PTM and gloss coefficient elaboration: All the computational work related to the analysis of the captured image data, consisting of the PTM fitting procedure and the gloss coefficient estimation, is based on a program written in Matlab [10] for first experimental development. For reasons of performance the code will be implementet in C++ and integrated in a image server compliant to the International Image Interoperability Framework (IIIF).
- Visualization: The visualization can be done in a modified version of the CHI RTIViewer software [7] or in a web-browser (Chrome, Safari or Firefox) with a modified version of WebRTIViewer [11], those already existing software components have been modified to be able to display the final result with the new enhanced technique proposed later in this document.

Methodology

To capture an RTI image we follow the procedure described in [3] and [4], while integrating it with standard image correction techniques.

- the calibration of the light source position is performed with a black glossy sphere. With such a black glossy surface it is possible to detect the highlight caused by the specular refection of a specific light source.

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- capture of a color target and applying the profile to the image data for color space transformation into a standard color space like sRGB
- the object of the acquisition is placed in position and a photo for each flash light is acquired;
- the photos are converted from the raw format to 16bit RGB-TIFF, in this process lens distortion correction, white balancing and lens color aberration correction are applied to the data acquired.

The diffuse component is modeled by the PTM coefficient that are calculated using the data collected from each light direction. The result of this first step is a set of parameters from a best-fit second order polynomial and a normal vector that represents the surface alignment. The coefficients - the 6-PTM coefficients and the normal - are defined for each pixel position and linked [5]. The existence of a gloss component is estimated by data analysis. Gloss can be distinguished from diffuse reflection by the distribution of the data points acquired. Recently on this topic there has been some research [12] [13]. However in our approach we limit our analysis to evidence based on our data. While diffuse surfaces show a smooth distribution, data of gloss must have at least a significant peak at a derived position, defined by the Helmholtz reciprocity principle. If gloss can be detected, a glossiness coefficient is calculated that represents the strength of gloss at a specific pixel position.
The visual appearance of a realistic surface is then composed in a three stage process:

- The diffuse component is calculated by the second order polynomial and the coefficients found for diffuse reflection,
- The normal vectors of the surface are generated using the PTM coefficients [5],
- The glossy component is generated based on a shading model derived from computer graphics. Therefore a virtual specularity is added based on shading model like phong [14] or similar any model [15]. The parameters of this model can be changed, within a range, by the user.
- The glossy component is saved in the same file where are the PTM coefficients.

To test our hypothesis several objects have been captured: A small mosaic with gold and stone tesserae, a oil paint, a matte white surface, some examples of fabric, a green leaf, and a wooden mask. This collection of examples allows to have a wide set of test materials, showing a variety of glossy and matte surfaces.

Viewer and User interaction

The strength of RTI is the possibility, for the user, to interactively change the light direction. This interaction is important to appreciate the quality of a glossy surface. Therefore we modified the existing RTI Viewer [7], a C++/QT software released in General Public License version 3, and the existing WebRTI Viewer, a web application written mainly in JavaScript using the SpiderGL library. SpiderGL[17] is a JavaScript computer graphics library for web platforms. It uses WebGL [19] (Web Graphics Library) for real time rendering. WebGL is a 3D computer graphics and 2D graphics JavaScript API (application program interface), compatible with a variety of web browser without the use of plug-ins. WebGL allows GPU (graphics processing unit) accelerated image processing and 3D effects as part of the web page canvas. Therefore it is possible to interact with other HTML elements or other parts of the page.
A web-based approach is crucial for such an application. It opens new possibilities for the dissemination of the digital reproductions and it makes a specific binary executable application unnecessary. This is a big advantageous not only for the integration of such a viewer in another environment, like a Virtual Research Environment (VRE).
Our software (schematically represented in figure 2) implements

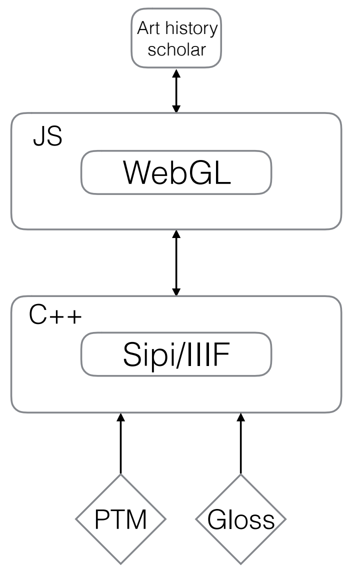

Figure 2. *The software model*

controls that allow the user to change the magnitude of the secular and diffuse part of the digital representation. These are updated in our viewer allow the user to modify the three typical parameters: α, which is a shininess constant for this material, which is larger for surfaces that are smoother and more mirror-like, when this constant is large the specular highlight is small, k_d which is a diffuse reflection constant , k_s which is a specular reflection constant.
One important feature of the development is performance, maintainability and stability. Therefore a specific IIIF server as a distinguished layer is in development. A IIIF web service returns an image in response to a standard HTTP or HTTPS request. The URI (Uniform Resource Identifier - an array of characters used to identify a resource) can specify the region, size, rotation, quality characteristics and format of the requested image. A URI can also be constructed to request basic technical information about the image to support client applications[16]. This server will be able to compute RTI image data based on uploaded single images and it provides the web viewer with the necessary image data.

Conclusions

The quality of our approach will be tested using a qualitative comparison method. The art historian user can change the free parameters using a GUI (graphical user interface) in the WebRTIViewer. This affects the gloss appearance and triggers a

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discussion on the specific object. Art historian interest is oriented towards the possibility of distinguish between different appearance of materials, more than a exact measurement of the reflectance proprieties. To exemplify this concept it is usefull to think about a mosaic with gold tesserae and matte stone tesserae. The gold tesserae have a different reflection behavior then the matte tesserae, because they have a stronger specular component. Therefore to visualize the visual effect of a whole mosaic it is important to assign different gloss components to each tesserae. From the perspective of an art historian scholar this is more important than the fidelity of the reflectance model. A quantitative comparison method is also currently under development. This will allow the comparison of each photo acquired by the experimental set-up with an image elaborated using our viewer, resulting in an index that measure the adherence of the model to the data.
The advantage of the proposed approach is its robustness and its simplicity. A complex function, that is able to describe specular and diffuse reflection, can unlikely result in an convergent solution, leading to instabilities in the fitting process. In addition, such an approach can be applied with most technologies known from computer graphics. The most interesting and promising is certainly WebGL. Web technology is the key to environments that allow an evaluation of the digital representations of artwork, like Virtual Research Environments. A VRE that has been developed at the DHLab is Salsah [20]. With Salsah, RTI images can be annotated, enriched with comments and they can be interlinked with other objects.

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Author Biography

Peter Fornaro is deputy head of the Digital Humanities Lab of the University of Basel. He is doing research in the field of digital archiving, imaging, cultural heritage preservation and computational photography. Fornaro is teaching at the University of Basel. Besides research and lecturing he is giving consulting to companies, archives and museums.

Andrea Bianco is a PhD student in experimental physics at the Digital Humanities Lab. He studied particle physics in Trieste and he worked as a R&D Engineer. He has a good knowledge of several programming languages, image and signal analysis and electrical engineering principles.

Lukas Rosenthaler is the head of the Digital Humanities Lab of the University of Basel as well as of the Swiss National Data Curation Center for the Humanities. He is an expert for data base systems, virtual research environments, image processing and digital archiving and he is supporting open access initiatives.