Metallic Reflections in the City

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ABSTRACT

After a short but fundamental description of the optical properties of metals, semi-metals and alloys based on the example of the Luxor Obelisk, we describe a certain number of visual effects and link their origins to the fundamental optical properties of the complex indices of refractions of metallic materials. Conceived as a beacon in ancient Egypt, the obelisk today is erected in Paris and oriented according to the cardinal points. Formerly topped by an electrum-plated pyramidion, but now covered in gold leaf, this small pyramid situated 23m above ground level reflects the sunlight in such a way that it was, and still is, visible from dozens of kilometers away. By focusing on this concrete example, we demonstrate that the aspect of materials, in this case metals, cannot be reduced to the concept of color, and even less to that of trichromatic color. Our goal is to outline the entire predictive rendering process and, via a concise demonstration, to present the key concepts of physics that must be met to generate a computer image that is identical to a photograph of an actual scene.

1. INTRODUCTION

For many years our research has focused on realistic materials rendering based on solid-state optic and theoretical models. Our aim is to accurately qualify each step in the predictive rendering process. To do so, spectroscopic ellipsometry is used to precisely characterize a perfectly smooth metallic material. Using these measurements and physically-based illumination models, we can accurately render a 3D scene whose description includes the spatial and spectral properties of the materials and light sources. As the interaction between light and matter depends on shape and surface state, complex and surprising visual effects occur. Such effects are highly evocative and deeply alter our understanding of what happens when light and metal simultaneously interact. In this paper, we rely on a unique example: the pyramidion of the Luxor Obelisk, at the Place de la Concorde in Paris. Computer graphics have only recently taken into account the polarization of natural light and metallic reflections (Berger 2012), whereas the usage of formal optical properties for simulation, via virtual metallurgy modeling, was introduced in the early part of this century (Callet 2002). Combining measurements of light polarization, complex indices of refraction, high-dynamic-range imaging (HDRI) and spectral imaging allows us to obtain accurate new simulations called predictive renderings. A set of spectrally-computed images, digital pictures and data curves give us a good understanding of the phenomena involved in the interaction of light and metal.

2. METALLIC MATERIALS AND DATA ACQUISITION

The only proved way to scientifically simulate the optical effects of metallic surfaces is to use the complex index of refraction (real (n) and imaginary (k) parts); yet little highly-accurate index data is available. To guarantee material property characterization, we sampled a particular gilt surface similar to the aforementioned famous

(1) a natural gold-silver alloy
(2) n = n + ik

monument. Offered to France in 1836 by Mehemet Ali, vice-regent of Egypt, Luxor Obelisk is erected in Paris, Place de la Concorde. In Egypt, the monument acted as a beacon and was oriented in relation to the cardinal points. The electrum-plated pyramidion, at the top of the obelisk 23m above the ground level, reflects the sunlight in such a way that it is visible from dozens of kilometers away. As the pyramidion of the Luxor Obelisk was originally covered by electrum, we used spectroscopic ellipsometry on a very tiny piece of natural electrum belonging to the Museum of Mineralogy at Ecole Nationale Supériure des Mines de Paris (Figure 1). At this stage, we are able to simulate the optical appearance of any element described in the periodic table as long as its complex index of refraction is known. As the optical properties of alloys are more complicated to compute, we studied models, which are relatively easy to comprehend for simple binary alloy cases such as brasses and bronzes; we furthermore conducted a more complex generalization of the n-ary alloy based on plasma physics. Since it is difficult to predict complex indices of refraction (mainly due to the multiple crystallographic arrangements of atoms), we chose to use spectroscopic ellipsometry to measure these essential indices. For more than fifteen years we have been measuring and compiling the complex indices of refraction of numerous physical samples of metallic materials. This method can also be used to acquire excellent optical data for minerals with a metallic sheen (sulphides, oxides, hydroxides, etc.). We also studied their surface states and produced spectral simulations that can be of use in a wide array of fields, including automotive, architecture, design, science and technology. This allowed us to clear up a certain number of misconceptions, such as "the only characteristic of specular reflection would be those of the light source". When light is reflected several times over by a material surface according to Snell-Descartes law, we can observe a phenomenon we will call "spectral multiplication". In such situations, the observed color saturation increases exponentially with the number of inter-reflections.

Figure 1: Electrum. Ellipsometric measurements were made on a very small scale (center piece of the picture) of alloy from the Museum of Mineralogy at Ecole des Mines de Paris.

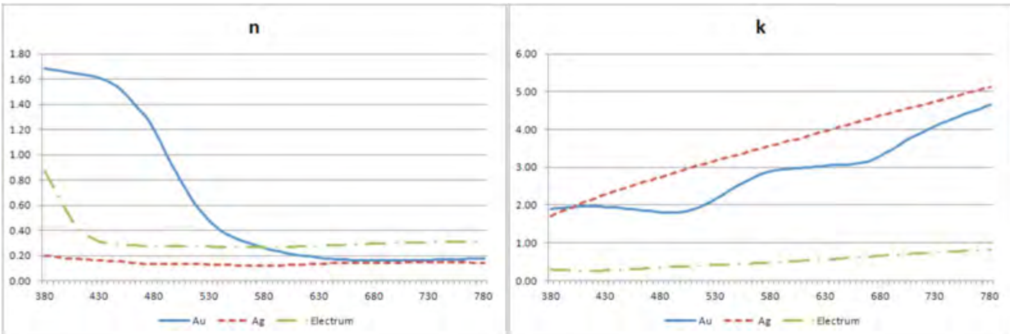
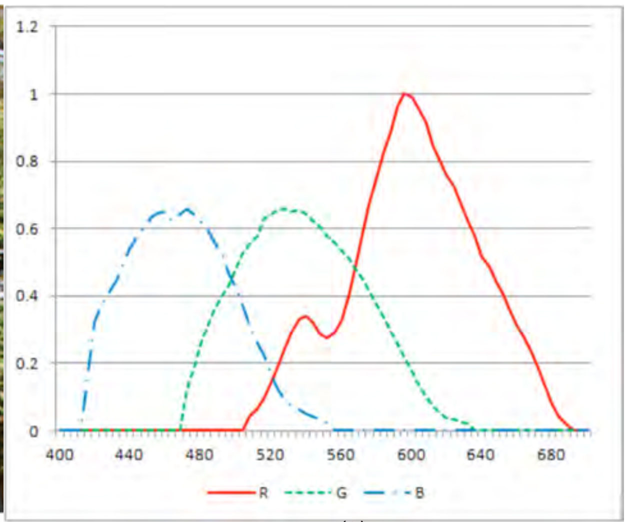


Figure 2: The compared real parts (optical indices) of the complex indices of refraction of Au, Ag and electrum (left). Idem with the imaginary parts (absorption indices) (right). Au (blue), Ag (red), Electrum (green)

3. LIGHT AND ENVIRONMENT CHARACTERIZATION

Having determined an accurate method for predicting the optical properties of metallic materials, we now need a spectrally-defined lighting environment for the rendering phase. As scattered atmospheric solar light is also polarized according to the sun's position, we need to create new kinds of environment maps. Two methods are taken into consideration to produce these environments: models and measurements. In this paper we use the Preetham sky model (Preetham 1999), updated by Hosek and Wilkie (Hosek 2012). In the next step, we will compare the models to the measurements provided by to a device we are currently developing, the SPLIS (Spectral Polarized Light Image Sensor). It is designed to acquire half-environments in two minutes, using 16 spectral bands and 4 polarization directions in HDR mode. A picture of the SPLIS device is given in Figure 3(a).

(A)



(B)

Figure 3: The SPLIS (Spectral Polarized Light Image Sensor) device during tests – still under development (a). The spectral sensitivities of the Canon EOS 5D Mark II camera (b)

4. RESULTS AND DISCUSSION

To obtain the final image presented in Figure 4 and 5, we applied the previously-described method to the spectral computations of an electrum, a gold and a silver plated pyramidion. Then, the results are converted to the RGB space according to the camera's relative spectral response curves, Figure 3 (b). In this case a Canon EOS 5D Mark II was used to take the actual photograph of the obelisk. The camera parameters (F/11; 1/400s; Iso 200; focal length 24mm) are also applied to the rendering, as are those of the sky model (Hosek 2012), in order to obtain the correct illumination of the actual sky on September 23, 2015, at 10:14am, in Paris. The surface state is described with a moderate roughness according to Beckmann model. With the SPLIS device we shall compare the direct spectral measurements of a real sky to the aforementioned models, and we shall reproduce a more accurate simulation of the optical properties of metals. This device, what is more, would also allow us to simulate a wide range of dielectric materials, which may be visible in the city at any given time. The SPLIS device can also notably detect the absorption of light in narrow spectral bands due to pollutants or water vapor.

(3) Ocean bidirectional path tracer - Eclat Digital Research
(4)https://confluence.lsstcorp.org/display/SIM/Cerro+Pachon+All-Sky+Camera+Project

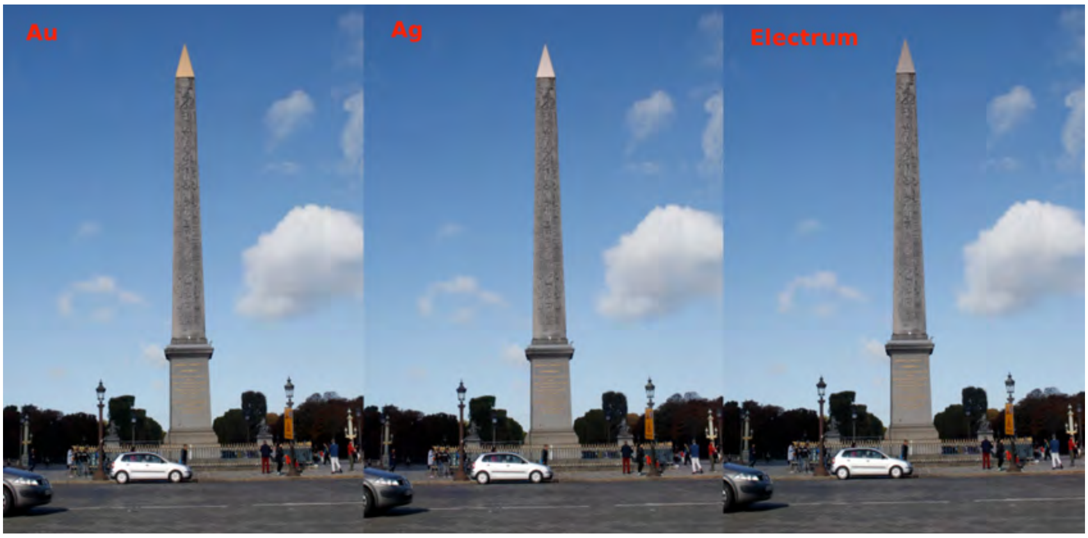


Figure 4: Retrieving the original optical aspect of the electrum plated pyramidion of the Louxor obelisk in Paris. Comparison is made with a gold and silver plated pyramidions placed in the same viewing and illumination conditions.

Figure 5: Simulation of electrum plated pyramidion under two exposure time (1/800s (top) and 1/3200s (bottom)) illustrating the obelisk acting as a beacon.

5. CONCLUSIONS

To correctly render the optical properties of materials, mainly metallic in this example, we use spectral computations requiring specific acquisition processes, from spectral material data (complex indices of refraction) to natural light, including its polarization states. We then built a new device, the SPLIS (Spectral Polarized Light Image Sensor), for computing the interaction between light and materials. This real light captured in urban spaces can be useful in many predictive situations (for building, lighting, thermal properties, pollutants characterization, etc.), as when light and metal simultaneously interact with shape, orientation, state of surface, and curvature, whether concave or convex, complex and surprising visual effects occur. Such effects are highly evocative and deeply alter our understanding of our perceptive experience. To conclude, a set of spectrally-computed images, digital pictures and data curves are proposed to allow us to more clearly and precisely perceive the phenomena involved in the interaction of light and metal.

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