Visual appearance of bronze -Simulation and validation-

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ABSTRACT

The visual appearance of bronze is studied, depending on their metallurgical composition and state of surface for some normalized illumination conditions. The results are presented on an example where a pluridisciplinary work was accomplished involving, engineering, art history, computer science, metallurgy, optics, material sciences, etc. specialists. Three academics labs, a museum, a rapid prototyping centre. The main results are presented here and summed up.using many images of the original artifact and the virtual and real replicas obtained. From 3D capture without any contact.to plaster replicas with a galvano deposited metallic film, the complete process is described with images and objects during the conference.

1. A PLURIDISCIPLINARY PROJECT

We present the main results of a complete study driven in cooperation with the "Musée National des Arts Asiatiques-Guimet" in Paris concerning a small metallic chinese statuette. Our object of study offered the opportunity of a collaboration involving metallurgy, optics, computer graphics, archaeology and engineering specialists. Replication of the original object using rapid prototyping methods and virtual optical aspect computations obtained, are described. The measurements on metallic reformulated tests samples and the corresponding rendering with our parallel and spectral ray-tracing algorithm illustrate the complete process of virtual restoration. That method was previously applied to the study of silver-lead alloys and gave very satisfaying results[2, 3]. Standard CIE specifications are used throughout the computations. Optical properties of the metallic surface are pre-calculated for an orthotropic ambient lighting and several illuminants[1]. No internal scattering of light exists inside metallic objects, so that their "own color" is a physical non-sense. Diffuse lighting and directional lighting influence are expressed for smooth or rough surfaces, according to Walsh (1926), Judd(1942) and Mandelis(1990) previous works. The simulated visual appearance of the metallic statuette is founded on the exclusive use of the complex index of refraction of each compound inside the alloys. Obtained by spectroscopic ellipsometry, these data are also acquired for several states of surface of the formulated metallic samples. Thus *effective optical constants* are used for the visualization of the roughness influence on the visual appearance for the same normalized lighting conditions. The scientific study concerns a small statuette representing a horse originating from China and dated of the "Fighting kingdoms period" (4th-2nd century BC). The obtained results are relative to reasonable hypotheses on metallurgical knowledge and practice of moulding with bronze[4] (Copper-Tin alloys) and depend on the relative concentrations of each species inside the resulting alloy. Some pictures whether captured from the real object or spectrally computed for 80 spectral bands using the digitized samples are given in appendix. The images, the test metallic samples and all the physical replicas will be presented during the conference.

2. THE MAIN PHASES AND RESULTS OF THE COMPLETE PROCESS, FOR VISUALIZING AND VALIDATING THE VISUAL APPEARANCE OF BRONZES.

1. 3D capture without contact with the museum statuette (Fig.1). This process was made in about 3 hours with a srtuctured light device from Breukman corporation. This gives 1 million triangles for representing the object surface with a high level of geometrical details.
2. Study and realization of a set of metallic samples in pure copper and 3 binary alloys with tin for 10-20 and 30 percent in mass concentration inside copper. A set of images obtained by spectral simulation are given in Figs. 2-5, including interflections from the virtual environment or not.
3. Optical Microscopy and Scanning Electronic Microscopy for metallographic structure and composition. In Fig. 6 are visible the islands of tin in an ocean of copper.
4. State of surface measurements by profilometry for each manufactured sample;
5. Optical constants measurements by spectroscopic ellipsometry on a polished copper sample and on each test sample with 10-20 and 30 % of Sn. For 2 rough samples, the same method leads to the **effective optical constants** of the metallic surface. This result is useful for the visual comparison between roughness influence as determined with the Beckmann and Spizzichino model of the scattering of light by a metallic rough surface and the current measurements. Increasing roughness tends to increase surface scattering of light and acts as a change in the visual appearance of lightness.
6. Physical replication by stereolithography of the original metallic statuette (SLA 500 device)
7. Elastomer mould realization and direct manufacturing of 4 plaster replicas by rapid prototyping
8. Metallic film deposition of several compositions on these plaster replicas by galvanoplasty (pure copper and 3 alloys). Artistic patination for one of the physical replicas. A photograph in Fig. 6 shows the replicas in a quasi similar presentation as in Figs. 2-3-4 They, however, differ by lighting conditions and the plane on which the objects are placed on.
9. Ambiant lighting modelling for synthetic image generation of the restored museum object. This was made using the SWR[5] (Surface of Whole Reflectivity) described as an extension of the previous resulted presented in 2001 AIC congress[1] and themselves extended from Walsh (1926), Judd (1942) and Mandelis (1990) works. The surface is drawn in Fig. 10. Notice that for noble metals the real part of the index of refraction over the visible spectrum has very low values (less than unity). There is no place here for describing all the properties of such a surface. The SWR results from the integration of the complex Fresnel reflectance factor for an orthotropic illumination over a smooth surface. The roughness of the surface acts as a « radio button » for modifying the mean angular and spectral reflectance magnitude R.
10. Spectral simulations with parallelized ray tracing software using 80 wavelengths bands of 5nm width. The virtual statuette geometrical data are hierarchically dispatch inside thousands of bounding boxes. This is made to speed up the ray-surface intersections determination.
11. Realization of a DVD presenting the main results of that project.
12. Public presentation of the virtual and physical replicas at the National Museum of Asiatic Arts-Guimet, in Paris.

References

1 P. Callet and R. Sève,"From mean diffuse external reflectance to color and visual appearance representation". AIC'01 Proceedings. SPIE, Rochester, USA (2001).
2 P. Callet and A. Zymla, "Rendering of binary alloys". Proceedings of ICCVG'04, Warsaw, Poland
3 P. Callet, A. Zymla, and A. Mofakhami, "Archeology and virtual metallurgy - application to the visulization of a work of art". Proceedings of ICCVG'02, Zakopane, Poland (2002).
4 M. MacRae, E. Arakawa, and M. Williams, "Optical properties of vacuum-evaporated white tin". Physical Review, 162(3):615-620 (1967).
5. P. Callet and O. Chassagneux, « On the Visual Appearance of Bronzes », proceedings of MIRAGE'05, INRIA Rocquencourt, France, 2005.

APPENDIX: MAIN RESULTS

3D DIGITIZATION, OPTICAL MEASUREMENTS AND COMPUTER SIMULATION

Figure 1. The original horse statuette at Guimet museum (15 cm x 14.5 cm x 5 cm).

Figure 2. Rendering of the alloy Cu70 Sn30 between Copper (left) and Tin (right)

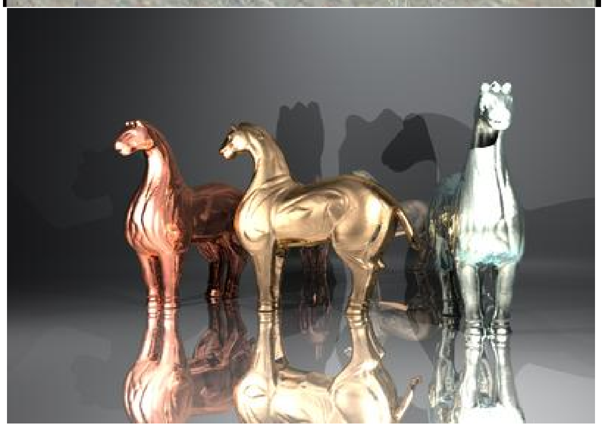

Figure 3: Rendering of the alloy Cu80 Sn20.

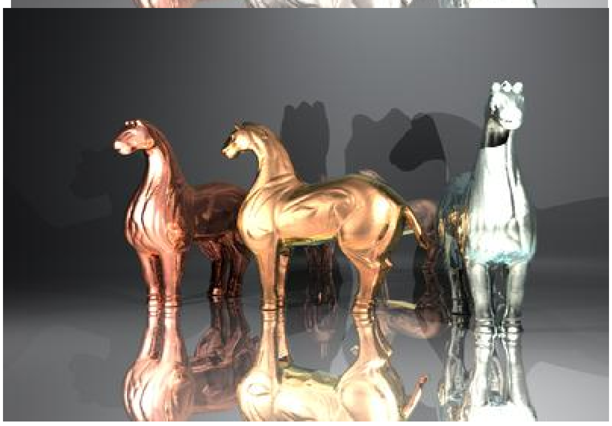

Figure 4. Rendering of the alloy Cu90 Sn10.

Figure 5. Influence of copper concentration from 70 (left) to 80 and 90 % (right) [simulation]

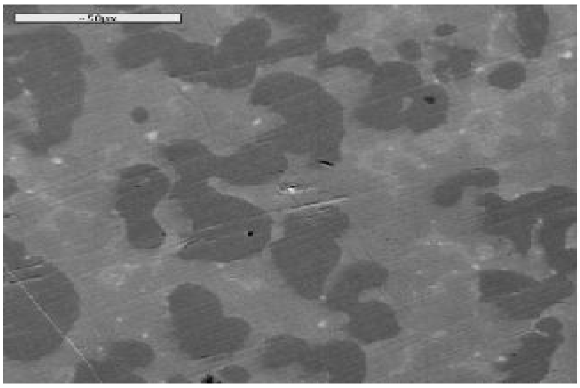

Figure 6 : SEM view of a Cu70Sn30 alloy

Figure 7. Photograph of the physical replicas

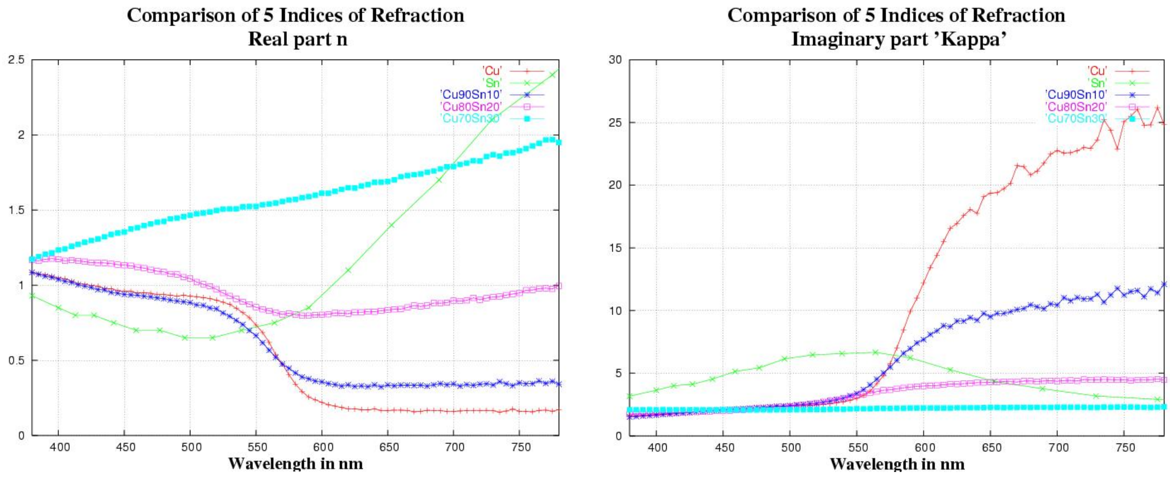

Figure 8. Complex Indices of refraction measured by spectroscopic ellipsometry for polished surfaces of Cu, Sn and three alloys.

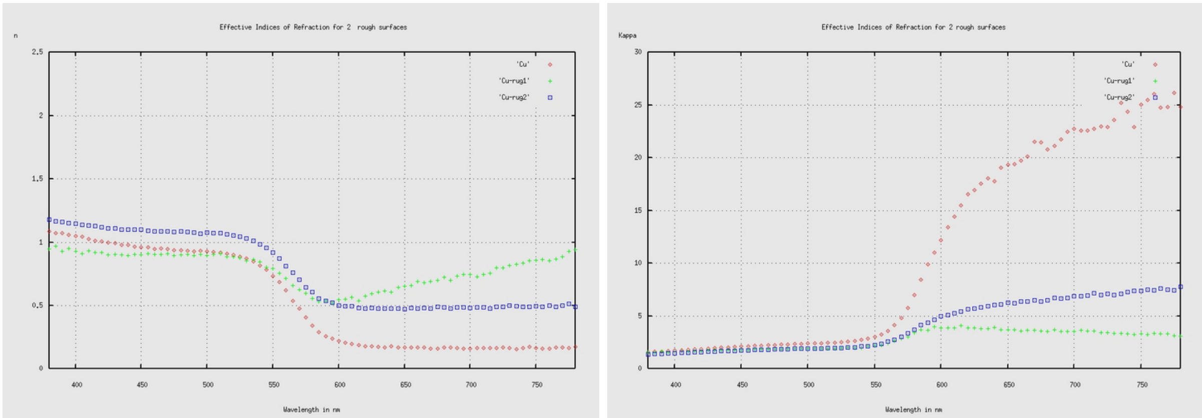

Figure 9. Complex Effective Indices of refraction for two rough surfaces of pure copper. A polished surface is used as an optical reference. Increasing rougness reduces saturation and increase lightness.

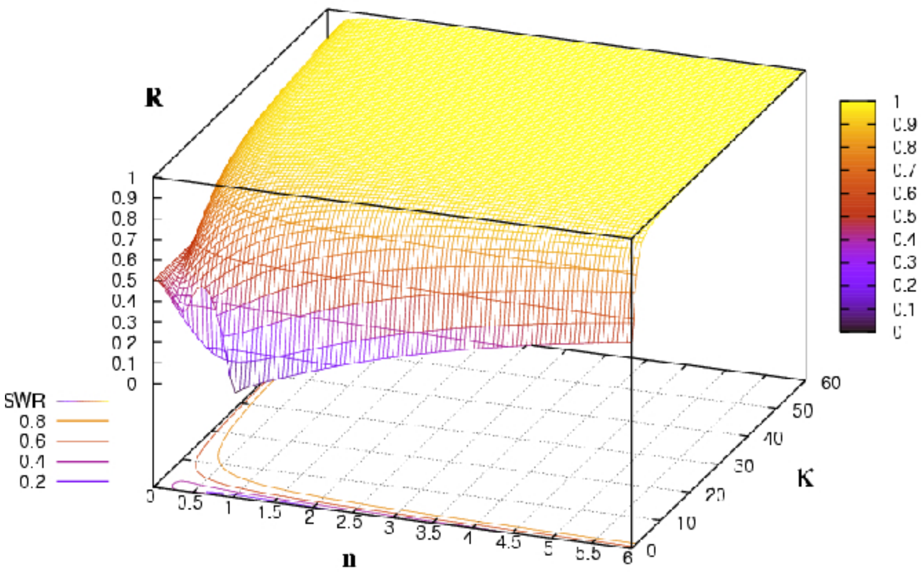

Figure 10. The Surface of Whole Reflectivity, drawn for n ranging in[0;6] and K in [0;60]