Real-time Visualization of Japanese Artcraft

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Abstract

We present several methods for simulation of Japanese lacquer ware, a prominent Far East Asian handicraft art. We consider two most popular kinds of Japanese lacquerware made by the makie and nashiji techniques. For rendering makie, we propose a method for preparing RGBA textures from digital photos of art items. The alpha channels of these textures control the weight with which color channels are blended with the measured bidirectional reflectance distribution function \( BRDF \) of a metallic finish. Both ray tracing and hardware based rendering are demonstrated. In the latter case, we show how the calculation of a sphere map texture used for \( BRDF \) visualization can be accelerated using a special coordinate system for tabulated \( BRDF \).

1 Introduction

From olden times lacquer work such as those shown in Fig. 1, commonly called urushi, has been used so widely for interior decoration, table ware and for other purposes that it is almost inseparable from the daily life of the Japanese. But urushi art of a highly artistic quality is inaccessible to the people in general, because the valuable materials, such as genuine urushi (lacquer juice), gold and silver, together with the skilled workmanship and the time required to make it, make its price almost prohibitive to them. However, in recent years cheap urushi art for utility purposes is being manufactured in large quantities for the use of the people who have a liking for anything new and novel. Because of this trend the merits of fine urushi art are gradually losing recognition.

Attracted by expressive beauty and richness of visual effects, which can be obtained using the old paints and techniques, we attempt to visualize the realistic appearance of urushi at interactive speeds. Realistic rendering of objects with complex optical properties, which change appearance with viewing and illumination directions, becomes of primary importance at early design stage and in electronic commerce. The specific properties of Makie technique include flip-flop visual color variation depending on viewing and illuminating directions while the properties of Nashiji technique include depth and sparkling effects. Very nice objects painted with very fine techniques consisting of mixtures of precious metals can be seen only in national museums. Since the production of such items took several years they can hardly be reproduced again. The other application of this research could be the computer-aided preservation of cultural heritage in digital form.

There have been many papers related to the modeling of metallic and pearlescent paints in CG literature, which make it possible to simulate all the optical effects observed on urushi paints. Those methods require huge number of rays to obtain the good approximation of material radiance. An approach for rendering the pearlescent and metallic appearance was proposed by S. Ershov et al. [3] where the \( BRDF \) is designed based on decomposing the paint layer into stack of sub-layers. Their method use the statistical approach for calculation of light scattering within the paint. However, their method does not focus on rendering itself.

The multi-image rendering algorithms such as light fields [7] and Lumigraphs [4] can capture the light distribution within the bounded region of 3-D space. The price paid for calculated light field at any point is the assumption of constant illumination and computationally expensive preliminary processing of input data,

Figure 1: Digital photographs of a jewelry box painted with makie urushi technique.
which cannot be computed on the fly.

The sphere environment map was originally developed by Blinn and Newell [1] to interactively show specular reflection of distant environment. The idea was later elaborated by generalizing the BRDF [10] but the technique does not work at interactive speeds.

This drawback was overcome with hardware acceleration and image based rendering described by B. Cabral et al. [2]. The authors used a sphere map which is view dependent representation. To avoid recalculation of the sphere map, the authors generate multiple sphere maps for different orthographic cameras. Afterwards, during a walk-through the sphere maps are interpolated using image based rendering (IBR) to ensure real time rendering. However, generation of reference sphere maps takes several tens of minutes.

Although, the above mentioned rendering methods can handle many optical effects that occur in urushi paints, they will fail to correctly visualize the depth effects caused by small metallic flakes dipped in lacquer.

We focus on a hardware based rendering, in which visualization of metallic finishes in Japanese lacquerware is done using a sphere map approach. Our approach to real time rendering of objects with complex appearance, like Japanese lacquerware items, includes online fast calculation of sphere maps. This widens the spectrum of possible applications to online ordering shape and design of lacquerware items.

Real-time visualization uses proposed blending of multiple BRDF's corresponding to each pigment used. First, the pattern of Makie which is painted on flat surface is taken by a digital camera. Second, the sphere map textures are generated by rendering a ball with a given BRDF and light sources. Usually, we have about three kinds of color pigments and metallic powder used in Japanese lacquer-ware. Therefore, we generate three sphere map textures mostly corresponding to gold, black, and red. Masking textures control blending of BRDF's with their alpha channels. Since gold powder and color pigment are usually mixed on the lacquer surface, we observe a flip-flop effect which means the changing of color from gold to that of the pigment depending on illumination and the direction of view. To simulate the flip-flop effect, we carefully set the alpha channels of masking textures using image processing methods. A multipass texture blending technique will be used because several textures must be blended on a surface.

The rest of the paper is organized as follows. Section 2 recalls the attainments on the urushi coating and decoration, in particular the makie surface decoration technique. Here we also summarize the most dominant optical effects that can be observed on the most urushi items. The BRDF representation using the adaptive grid and the fast calculation of the sphere map applicable to real time rendering of virtual urushi art items is described in Section 3. In Section 4 we propose the fast rendering technique of makie art drawings which can clearly demonstrate the metallic color shifts (flip-flop) effects. Finally, we present some results obtained using our approach and we conclude this paper.

2 The Urushi Coating and Decoration

The clear urushi is prepared from the sap of the lacquer tree by cutting the bark of tree. The cleared urushi from impurities is used for coating and decoration of the urushi art items mostly made of wood.

- **Makie - Sprinkling**: Makie is the most famous surface decoration in urushi art technique. Patterns are painted with clear urushi or the red urushi and then the fine silver, gold and other metallic powders are sifted and adhered over the wet pattern to decorate the surface. The powders are sprinkled by means of bamboo or horn tubes covered with silk screen, as well as with a brush dusting. There are many kinds of makie techniques differing mainly in what kind of urushi is used for pattern drawing and what kinds of powders are used.

- **Optical Effects - Flip-flop**: Makie urushi technique is a coating with complex optical behavior which includes flip-flop visual color variation depending on viewing and illuminating directions. The color variation is usually the smooth visual variation between two colors. Optical behavior of such paints is mostly described by a bi-directional reflectance distribution function. Other effects observed include the Fresnel reflections on solid paint.

3 BRDF Visualization

The focus of this paper is on real time visualization of real items in virtual world showing the complex optical effects during the walk-around the artistic item. Realtime BRDF visualization is needed for this purpose. This problem is solved by proposed coordinate system for BRDF representation adjusted to a method of fast calculation of a sphere map as described bellow.

3.1 BRDF Representation

The BRDF of a metallic urushi surface is directionally diffuse; that is, such a BRDF exhibits fairly sharp change near the specular direction. We have measured BRDF's using the setup described by Letunov et al. [6].

The tabular representation of BRDF using the spherical coordinate system ($\psi, \xi$) with polar axis along the surface normal and a uniform grid of points does not
provide good accuracy in a specular peak area, unless the grid density is very high, up to hundred thousand of tabular entries. The BRDF is represented in this system as \( f(\psi_i, \xi_i, \psi_o, \xi_o) \), where

\[
\overrightarrow{n} = \text{Surface normal},
\]

\[
\overrightarrow{s} = (\psi_i, \xi_i) \quad \text{is incident direction relative to } \overrightarrow{n},
\]

\[
\overrightarrow{o} = (\psi_o, \xi_o) \quad \text{is outgoing direction relative to } \overrightarrow{n}.
\]

The similar problems related to BRDF representation were considered by Rusinkiewicz [11]. He uses the parameterizing the BRDF in terms of the halfway vector between the incoming and outgoing rays and a \textit{difference} vector. We will consider the BRDF in terms of the specular direction and a local vector.

![BRDF representation](image)

**Figure 2:** BRDF representation. A special coordinate system for BRDF representation.

We can decrease the size of the discretized BRDF stored in a table to several hundred entries. Each value in a table is associated with the discrete coordinates \((\theta, \phi)\) of a rotated spherical coordinate system with the polar axis along the specular direction, as shown in Figure 2. The BRDF is represented in this system as \( f(\theta_1, \phi_1, \theta_o, \phi_o) \), where

\[
\overrightarrow{s} = \text{Specular direction},
\]

\[
\overrightarrow{o} = (\theta_o, \phi_o) \quad \text{is outgoing direction relative to } \overrightarrow{s},
\]

\[
\phi_o(\psi, \xi) = \text{Angle between } \overrightarrow{o} \text{ and } \overrightarrow{n} \text{ directions}.
\]

As a result of this parameterization a sharp peak of diffuse BRDF will be in predefined area of BRDF domain around the polar axis in a new coordinate system. We can then discretize the BRDF and adjust the grid density making it more dense for small values of \( \theta \), in other words grid will be dense near the specular peak and sparse in the areas far from polar axis.

This method provides a high and almost uniform accuracy of approximation and does not need as many grid points as it would be necessary for an uniform grid.

3.2 Sphere Map Generation

The **sphere map**, shown in Fig. 3, is an image resulting from an orthographic projection of a sphere whose surface BRDF matches that of the target object. The sphere is rendered for the same illumination and observation conditions as for the target object.

Next we restrict ourselves to the case of several directional light sources and distant point light sources. Therefore, calculating the lighting equation for the sphere radiance map [2] amounts to the classic ray tracing of the sphere.

To render a sphere map, we select a pixel from the sphere map, shoot a ray from the camera through this pixel, and find where it hits the sphere. At this point, we fire rays to all light sources and calculate the radiance from the sphere BRDF, the local normal, the viewing and illumination directions as

\[
L(\overrightarrow{\omega}_k) = \sum_k f(\overrightarrow{\omega}_k, \overrightarrow{\omega}_o) I_k(\overrightarrow{\omega}_k),
\]

where \( L \) is the radiance in the \( \overrightarrow{\omega}_k \) outgoing direction, \( f \) is the BRDF, \( I_k \) is the incident radiance of the sphere at the point hit by the ray, coming from the \( k \)-th light source, \( \overrightarrow{\omega}_k \) is the direction to the \( k \)-th light source.

3.3 Fast Re-calculation

If we could create a good mesh on the sphere and shade only few vertices of the mesh and then interpolate all other points, the sphere map generation could be extremely fast. Furthermore, the color interpolation between mesh points can be done in hardware with Gouraud shading.

Below we will focus on the problem of construction of a good mesh for a single light source. To obtain the sphere map for several light sources, we just repeat the whole process for each light source and superimpose the sphere maps using the blending operation.

Looking at a "typical" sphere map image, shown in left of Fig. 3, for a single light source we see that a fixed polar or rectangular mesh will not be optimal, because, like for BRDF, there is a small area with large intensity gradients where the mesh must be fine and a large area with small gradients where we can use a coarse-grained mesh.

An optimal mesh should follow the BRDF changes. The BRDFs for metallic paints have a very strong dependence on angle \( \theta \) in our BRDF representation, refer to Figure 2. Therefore, the best choice is the mesh with parametric lines along which the angle \( \theta \) is constant, i.e. \( \theta(\psi, \xi) = C_\theta \). The second family of parametric curves is naturally drawn from the highlight center along the constant angle \( \phi \), i.e. \( \phi(\psi, \xi) = C_\phi \). The points \((\psi, \xi)\) refer to the spherical coordinates relative to the \( \overrightarrow{n} \) on the rendered sphere. Unfortunately, such mesh is not uniform along the ellipsoidal curves for constant \( \theta \). The mesh is improved by discrete arc-length reparameterization of parametric curves \( \theta(\psi, \xi) = C_\theta \).

The resulting mesh derived for a measured BRDF of a gold metallic paint is shown in Figure 3 on right.
the number of light sources is no larger than ten, the time needed for calculation of a sphere map with our approach is a few tens of milliseconds for Pentium III machines with contemporary video cards.

![Sphere map](image)

**Figure 3**: Sphere map. Left: Sphere map of a gold metallic paint. Right: Mesh for fast calculation of a sphere map.

![Cross section](image)

**Figure 4**: Cross section of the makie urushi showing pixel covering the sample.

## 4 Makie Simulation

This section describes preprocessing of the lacquer digital image to obtain information about distribution of colored urushi, metallic finish, and hardware based rendering of the makie lacquer ware.

### 4.1 Acquiring Optical Information

The surface of a makie item is usually painted with one, two or three types of colored urushi and one type of metallic finish. We prepare samples for each of the types of colored urushi used in the item under study. In particular, we make a metallic finish sample where platelets are sprinkled in such a density that no free space between them remains. We make photos of these samples under the same illumination conditions as that of the item. Because illumination should not vary significantly over the place where the art item or samples are put, it is best to use daylight illumination. We then extract radiometric information in the form of a high dynamic range (HDR) image from photos of the item and samples. If there is no too bright or too dark pixels on the image, then simple gamma transformation is enough. This is because CCD matrices are highly linear, so nonlinearity is added by the camera circuitry at the output, and this nonlinearity is only often gamma correction - at least, in some range of medium lumnances. Further calculations are done either in XYZ or any RGB space, such as that of the camera after gamma transformation, obtained from CIE XYZ by a linear transformation.

Colored urushi paints are not intermixed on make; different types of it are applied on different places. The color of each colored urushi varies over its patch only slightly because the application conditions such as, the layer thickness vary only slightly. On the other hand, the metal component of the finish consists of small thin (micrometers) platelets glued to the surface of colored urushi. In some types of urushi, pigment particles are also glued on the colored urushi after metal particles have been sprinkled on it. Figure 4, shows how sprinkled metal particles of makie are covered by a pixel of a CCD matrix in a digital camera. As a result, the colors of metallic and pigmented finishes mix additively rather than subtractively. This means that if metallic platelets occupy some fraction $p$ of the colored urushi surface, then the BRDF $f$ is a weighted sum of the BRDF of the metallic finish $f_{metallic}$ and those of colored urushi:

$$f = p f_{metallic} + \sum q_i f_i,$$

with $p, q_i$ being positive scalar weights. $f_i$ is the BRDF of the $t$-th colored urushi, and $q_i$ is the fraction of the surface occupied by it. More general approach was considered by Lensch [5] were they used the image-based measuring method for BRDFs. We will consider $f_{metallic}$ as given from measurements and all other basis elements and weight must be estimated.

### 4.2 Selection the $f_i$ Basis and Coefficients

Given the BRDFs, the radiance of a pixel in HDR image can be calculated as the BRDFs summed with lighting and integrated over the surface area covered by the pixel projection. Therefore, the radiance for three color channels is

$$T(i, j) = p(i, j) \mathbf{m} + \sum q_i(i, j) \mathbf{c}_i,$$  \hspace{1cm} (1)

where $\mathbf{m}$ and $\mathbf{c}_i$ are color triplets of a surface covered by only metallic finish and by only the $t$-th colored urushi, respectively. Therefore, positive weight are constrained by $p + \sum_i q_i = 1$ at pixels in drawing and $p + \sum_i q_i <
at boundary pixels. Our goal is to find \( p(i, j) \) and \( q(i, j) \).

To this end, we change the basis of the three-dimensional color space used in such a way that \( \mathbf{c}_l \) become basis vectors. At this point, we recall that most makie items have no more than three types of colored urushi. If we assume exactly three, then a new basis has three vectors collected in a matrix

\[
A = (\mathbf{c}_1^\prime \mathbf{c}_2^\prime \mathbf{c}_3^\prime).
\]

At this point, we assume that the HDR color of metallic finish \( \mathbf{m} \) is contained in the convex hull of basis vectors \( \mathbf{c}_l, l = 1, 2, 3 \). Usually, this is so because \( \mathbf{c}_l \) are either some red, green and blue colors or some red, green and white colors, while \( \mathbf{m} \) is goldish.

Therefore, by multiplying the Eq. 1 from left side with inverse matrix \( A^{-1} \) we have the equation in new basis

\[
\mathbf{T}'(i, j) = p(i, j)\mathbf{m}' + \sum_{l=1}^{3} q(i, j)\mathbf{c}_l,
\]

where

\[
\mathbf{T}' = (T'_1, T'_2, T'_3) = A^{-1}\mathbf{T}, \\
\mathbf{m}' = (m'_1, m'_2, m'_3) = A^{-1}\mathbf{m},
\]

and \( \mathbf{m}' \) is the triplet color of the metallic finish with respect to the new basis. The coordinate vectors \( \mathbf{e}_l \) are the unit vectors \( \mathbf{e}_1 = (1, 0, 0) \), \( \mathbf{e}_2 = (0, 1, 0) \), and \( \mathbf{e}_3 = (0, 0, 1) \).

Now we recall that colored urushi patches are not intermixed. Therefore, if we knew the fraction of metallic finish for each pixel \( p \) exactly, we would find that, in the limit of infinitesimally small pixels, only one of \( q_l \) should be nonzero for any pixel. In reality, because the color of colored urushi \( \mathbf{c}_l \) is not absolutely constant and two or three color patches may meet at a pixel, more than one \( q_l \) are nonzero. But, for most pixels, we have the largest \( q_l \) for the colored urushi that is actually present in the area covered by the pixel and other weights are small or zero.

Noting that \( q_l \) are positive, we can approximately find \( p(i, j) \) as

\[
p(i, j) = \min\{T'_1(i, j)/m'_1, T'_2(i, j)/m'_2, T'_3(i, j)/m'_3\}.
\]

The obtained \( p(i, j) \) values are actually the alpha values of the generated texture shown on center of Figure 5. The second term of Eq. 2 after linear transformation to the monitor RGB is the RGB residual texture shown on right of Figure 5. The alpha component and the RGB image form the final RGBA texture.

![Figure 5: Texture decomposition. Left: Digital photo of a pattern. Center: Alpha channel used for weight of metallic BRDF. Right: Pattern without the metallic components.](image)

### 4.3 Rendering Makie and Colored Urushi

Our approach employs a texture for rendering the Lambertian reflectance of colored urushi (see bottom of Fig. 5) and sphere map texture (see Section 3) for visualization of measured BRDF of metallic (gold or silver) finish. For controlling the ratio between two types of reflectances, we use the alpha channel of the texture calculated from Eq. 3. Thus, in our implementation we render objects of arbitrary geometry using multi-tex- turing method, one texture mapping uses the metallic sphere map and the other one is ordinary texture mapping with residual texture. The two texture images are then blended together according to the alpha channel.

The artistic drawing should be captured from flat areas for correct mapping to more complex geometries. The rendering runs in real time with different geometries.

### 5 Results

The proposed method for Makie visualization have been implemented as our real-time visualization system using Java3D. Users can observe the color shifts by rotating the object in real time as can be seen in Figure 6.

Figure 7 shows a frames from real time visualization of Japanese showing the color changes of simulated makie technique with the flip-flop effect.

### 6 Conclusions

We have described new methods with focus on real time visualization of real artistic items in virtual world showing the complex optical effects. We consider most popular technique of Japanese lacquerware called the makie. We described interesting optical effects that can be observed in this technique, and which can be simulated by the proposed multi-texturing methods.

Real-time BRDF visualization method based on color interpolation between the vertices of an adaptive mesh on sphere map image was developed.
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